HYDRAULIC RAMS

THEIR

PRINCIPLES AND CONSTRUCTION.

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INCLUDING SOME EXPERIMENTS CARRIED OUT BY THE AUTHOR AT THE REGENT STREET POLYTECHNIC AND VARIOUS PARTS OF THE COUNTRY.

BY

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PREFACE.

THE Author, when a boy, was fascinated by the working of a hydraulic ram, which he had frequent opportunities of seeing, near his home in the country; since then he has had to do with a great many, both old and new. The experience he has gained in practice, and from a large number of experiments with a ram especially fitted for the Regent Street Polytechnic, has been of great value to him for both practical and lecturing purposes.

Thinking the subject matter of this little book would be of interest to his fellow-workers it was published in the "*Plumber and Decorator*," and, as it has been asked for, it is now issued in its present handy form.

No claim is made to literary merit, but the Author hopes this may be found useful, and meet with the same kind reception that has been accorded his other books.

J. WRIGHT CLARKE.

November, 1899.

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HYDRAULIC RAMS.

A HYDRAULIC ram is a machine with no moving parts, excepting two working valves and sometimes one air valve, and is used for raising a portion of the water which works it to a height, such as from a valley to a cistern in a house, or a reservoir or water tower, in some elevated position.

Before describing the ram and its capabilities it will be advisable to explain certain principles in hydro-mechanics and thus help to make the action more clearly understood.

In earlier lectures the principles of what is commonly known as "water-hammer" in pipes were explained, and also the appliances used by plumbers for preventing the objectionable noises made when the flow of water in pipes is suddenly arrested.

In those lectures the action of air vessels was explained and also their object, which is to slowly arrest the impetus, or momentum, of the water moving in a pipe when a cock attached to it is suddenly closed.

If, instead of fixing an air-vessel to the service-pipe, and near the bib-cock, the end of the pipe was continued upwards above the level of the cistern, or reservoir, as shown by diagram, Fig. 1, and water allowed to flow out of the cock, on quickly closing the latter the water will rush up the pipe A, to a considerable height above the level of that in the cistern, and then subside again to the level line.

As another illustration, it has been found in

practice that where a service-pipe from a cistern had an air-pipe fixed below the stock-cock, as at B, it has been found necessary to turn the end, out of which water spouted, over the top edge of the cistern, when a bib-cock on the service-pipe has been suddenly closed.

When arranged as shown in the diagram the water nearly all runs out of the pipe A, when the bib-cock is first opened. But when suddenly

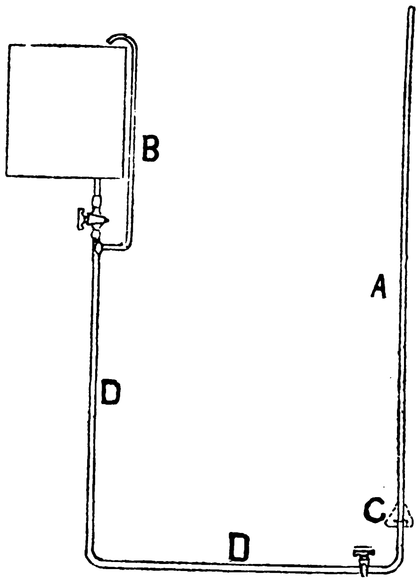

FIG. 1.

closed the water will rush up much above the cistern level, having only an air resistance, and, unless the pipe is continued high enough, escape out of the top end.

By fixing a valve, which opens upwards, where shown by dotted lines at C, the water is retained in the pipe A, so that the latter does not partially empty when the bib-cock is opened. By constantly opening and suddenly closing the

latter a considerable quantity can be raised to a height above the level of the cistern. But, as the water in the pipe is in a state of inertia, or motionless, some of the power is spent in putting it in motion, and not so much is driven out of the top as would be the case if an air-chamber was fixed just above the valve at C.

The longer the pipe D D, and with a clear way bib-cock, not less in diameter than the pipe, the greater the height to which the water would be raised.

To still further show the power of water, when suddenly checked it is only necessary to recall memories where lead-pipes have been split in the sides, and after repairing or renewing them, had again to repeat the repairs or renewals. The writer has samples of lead-pipes split both longitudinally and transversely. A sketch of a ¾ in. lead bend is shown by Fig. 2,

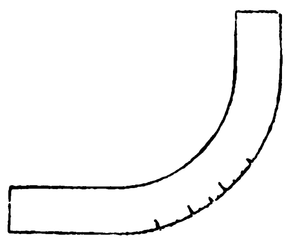

FIG. 2.

and that the cracks were not from any defect in the manufacture of the pipe or workmanship, when making the bend, was evidenced by bending other portions of the same pipe without any defects being found. It is for such reasons as this that screw-down valves are sometimes preferred to cocks with keys, as they are closed more slowly. By these illustrations it will be understood that moving water has considerable force. In the example shown by Fig. 1, the water in the pipe D D, is first put in motion by gravity, and, being in motion, has neither the will nor the power of itself to stop, but keeps moving until an opposing force takes effect.

The opposing force in this case being gravity, or the earth's attraction to itself, added to the weight of the water in the pipe A; the latter absorbs some of the power from the moving water and is itself put in motion.

The contents of the two vertical pipes when at rest are in a state of equilibrium and the two columns balance each other. But when that in D is in motion, its weight plus its momentum is in excess, pushes its way through the valve C, and forces up the water above whenever the bib cock below is closed quickly.

And this is really what takes place in a hydraulic ram, but in this case the action is

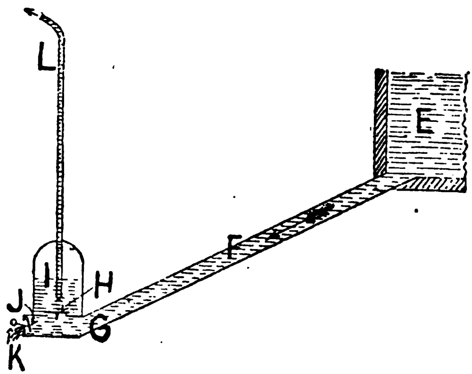

FIG. 3.

automatic, that is, self-acting and not actuated by any appliance worked by hand, as the opening and shutting of a cock.

We may now deal with the construction of hydraulic rams.

It is not necessary for our purpose to give a history of them, or deal with obsolete patterns which served their day, but are now superseded by others of better form and capabilities. A drawing of one, see Fig. 3, is given, as it lends itself to a description of the working parts.

In the drawing, E is a reservoir of water which is a few feet above the level of the ram;

F is the "drive" or feed pipe; G is the body with a valve, H, opening upwards into the air-chamber, I. At J is a valve hinged at the top so that when entirely closed it covers the orifice or opening, and has a weight, K, on the end of an arm which acts as a lever, which added to the recoil of the water, causes the valve to open inwards into the body; L is the delivery pipe leading to a cistern, reservoir or other storage chamber.

The action is as follows:—When the valve, J, is opened by the weight on the lever, K, the water from E runs down the pipe F and escapes as shown in the sketch. After a fraction of a second in time the velocity so increases in speed as to force the valve, J, onto its seating, thus arresting the flow.

If the body of the ram, or the escape valve, was not made very strong it would be broken by the force of the water, which, being as nearly as possible incompressible, strikes a blow almost as hard as a mallet or hammer, which has a face equal in sectional area to the column of water, and has the same velocity and weight at the moment of impact. The strength of the ram is sufficient to resist this force at all points excepting at the opening beneath the air vessel. This being covered by the valve H, which is held down only by the weight of the water above, will allow a portion of the moving water to be pushed through when the force behind it is in excess of the weight above the valve.

If we assume that the weight above, which is pressing on the valve, is 50 lbs., it follows that the force beneath must be greater or the valve will not be lifted. And this force is derived from the weight of the moving water multiplied into the height it has fallen. And these factors must be large enough to raise the valve, H, and force a portion of the water through.

As soon as the motion of the water in F has been arrested, when a slight recoil takes place, the weight of the water alone, not being sufficient for keeping valve H open, it closes, and at the same time, the contents of the drive pipe being at rest and only the dead weight of

water pressing against the valve J, the latter opens by the weight K, aided by the recoil above mentioned, when the flow down F again commences and the whole action is repeated. This goes on for an indefinite time so long as the water supply is sufficient and the ram is in working order and adjustment.

We will deal with the construction of modern rams presently, and now proceed to describe their fitting up, commencing with the drive

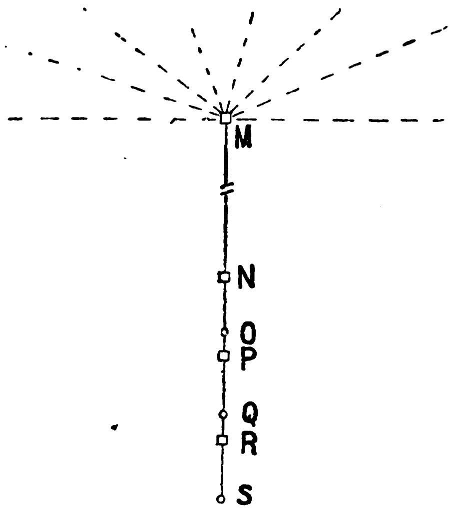

FIG. 4.

pipe. The writer had to do with a case a few years ago where the water was collected from springs on a hill side and conducted into a filter tank for catching sand, &c, the arrangements being as shown by Fig. 4. The dotted lines represent ordinary agricultural pipes with open joints leading to the cement lined brick built filter tank M, and thence to the feed tank N about a quarter of a mile away. The tank N supplied a medium size ram at O, and the tail water ran into the tank P, which supplied

another ram Q, thence to tank R, which worked a small ram at S. The available water supply being limited and not sufficient to drive a large ram, and the falls being suitable, a series of three rams was fixed, those lower being worked by the tail water from those above.

The end of the drive pipe in each feed tank had a hinged drop valve for stopping the supply to the ram with which it was connected, the

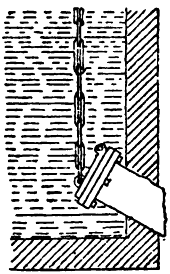

FIG. 5.

water then running out of an overflow into the lower tanks and thence to a valley. Fig. 5 shows the drop valve fixed in the tank and having a chain for opening.

Many rams are fixed by the sides of rivers, a suitable place being near "locks," when a "head" is formed above the "gates" and the waste can return to the river below the locks. The same result is obtained by damming back the water in a brook or burn. In each case a tank and drop valve are provided on one side of the stream.

Some time ago the writer had a ram fixed which was driven directly by the water from a lake of several acres in extent, as the cost of a tank could not be afforded. The end of the pipe was submerged about 2 ft., and had a copper wire grating fixed as shown at T, Fig. 6.

As an extra precaution for keeping dead reeds and rushes from being drawn in, an outer grating was fixed as shown by the laced lines. This practice, however, is not to be recommended, as only those which come broadside on are intercepted, those floating endways passing through the meshes of the netting. Neither is it convenient to have a valve on the extremity of such a pipe.

In this case a clear way sluice valve was fixed in the drive pipe close to the ram. This valve should always be fixed as stated, as it saves a great

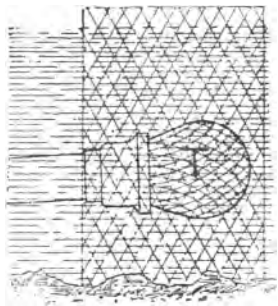

FIG. 6.

deal of time when making repairs or adjustments and obviates the trouble of going backwards and forwards to the tank for starting and stopping purposes.

Valves for this purpose should have a clear, straight way through, so that the direction of the current is not changed, as is the case with many kinds. Neither should there be any parts where air can accumulate, and which would act as a spring buffer and rob the "shock" of the water of some of its force. For this reason the valve should be fixed sideways, that is, the spindle should be horizontal. The valve would probably

require repairing or renewing at times and should have screwed unions, or flanged ends fixed by bolts and nuts, so that its removal can be done without breaking any part of the pipe or ram. A side elevation of a valve with flanged ends for fixing to a cast iron pipe is shown by Fig. 7.

Sometimes indiarubber rings are used for packing the flanged connections, but this, being a soft material and "giving" a little at each shock, absorbs some of the power of the waters' motion when arrested by the action of the ram.

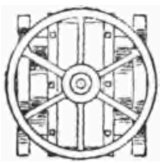

Fig. 7.

The flanges could have "trued" faces, so that no packing is required, but as these sometimes rust and "grow" together, a "millboard" packing is an advantage, in that the separation can be more easily made. When brass or gun metal cocks for connecting to lead pipes are used, they should have ground-in unions which do not require any washers or packing.

When the drive pipes are made of lead they should be very strong and not less than the following weights:—

$\frac{3}{4}$ in.,	9 lb.	per yard.
1 in.,	12 lb.	„
$1\frac{1}{4}$ in.,	16 lb.	„
$1\frac{1}{2}$ in.,	21 lb.	„
2 in.,	28 lb.	„

and the joints should be "wiped" and not copper-bitted.

If made of plain wrought iron the pipes to be "steam" strength, and they should be a size

larger than when lead is used to allow for corrosion by rusting, which reduces the water-way and interferes with the motion of the water. It is better, too, when such pipes are galvanised to have them a little larger than when made of lead, owing to their being rough inside.

When necessary to have them 2 in., and larger, it is usual to fix cast-iron drive pipes, not only as an economy but as being less liable than lead to sag in soft or boggy earth, or be lifted by roots when near trees. It is important that such pipes should be laid so that no air can accumulate in them, as would be the case if any parts were either raised or lowered so as to form bags or traps.

Cast-iron pipes should be protected as much as possible from rusting, for reasons already given, and also because of pieces of rust passing into the ram and interfering with the seating of the delivery valve in the air chamber. This takes place more especially after the ram has been unused for a time. Even when, owing to some disarrangement, it has stopped for a day or two a quantity of rust has given trouble on re-starting.

Cast-iron pipes coated inside with a wash made of freshly slacked lime have sometimes answered very well. When done in a proper manner with the solution suggested by Dr. Angus Smith they are very good, but a great deal depends upon the method of coating. This should be done in the foundry, where the pipes are cast, when they are hot from the moulds. When done afterwards, or painted by hand, the pipes frequently rust, and complaints have been made of a taste of the coating material being imparted to the water.

Cast-iron pipes with flanged ends are sometimes used as drive pipes, the flanges being bolted together with a packing between. The proper way for making such joints was described when writing on sluice valves.

Socketted pipes are those mostly used, and they should be very strong or they would break under the water shocks inside.

The dimensions and weights should be not less than as follows :—

Inside diameter in inches.	Length exclusive of socket.	Thickness in decimals of an inch.	Weight per length.		
	Feet.		Cwt.	qr.	lb.
2	6	·31	0	1	20
2½	6	·33	0	2	7
3	9	·35	1	0	3
4	9	·39	1	1	24
5	9	·42	2	1	5
6	9	·45	2	2	0

The joints on cast-iron socket pipes are, when not coated with Smith's solution, sometimes made with rust cement. When the pipes are coated the cement does not "rust" properly, and the joints are not at all good under those circumstances.

The constitutents of the cement are sal-ammoniac, flour of sulphur and iron-borings from an engineer's shop. When the latter are "oily" they should be made red hot to burn off the oil. The proportions should be carefully attended to, as if the cement is made too strong it will rust with such violence as to burst the pipe sockets.

The proportions for medium setting cement are by weight as follows:—

1 powdered sal-ammoniac.
2 flour of sulphur.
100 iron borings.

And for slow setting :—

2 powdered sal-ammoniac.
1 flour of sulphur.
200 iron borings.

Sometimes urine is used instead of sal-ammoniac.

When coated pipes are used, caulked lead

joints are the best. The sockets should have a groove inside as shown at U, and the spigot a bead on the end, as at V, Fig. 8. When making such joints care should be taken to have the bore of the pipe properly aligned, so that there are no sharp edges inside for the water to impinge against and cause eddies.

When making caulked joints it is usual to first "yarn" them. That is, drive, or caulk into the annular space between the pipe end and socket a few strands of yarn, or loosely twisted soft rope, as shown at W. This is for the pur-

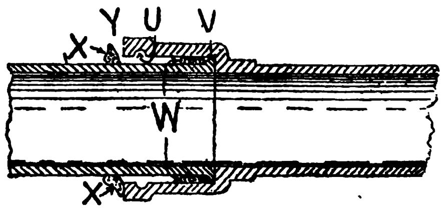

FIG. 8.

pose of preventing the molten lead getting inside the pipe. Too much yarn should not be used or the joint will be weak, as less lead can be run in. Because of this the writer has seen the lead driven out of the joint by the shock of the water inside.

After yarning the joint a clay band is usually placed outside, as shown at X, and molten lead poured into the opening left in the top at Y. The lead shrinks as it cools, and to make it fit tight is "staved" on the exposed surface to make it expand and fill up the socket.

As yarn will rot away in time, and when tarred imparts a flavour to the water, a better joint is made by caulking the bottom of the socket with pieces of rod lead, or with thick sheet lead cut into strips about half an inch wide. Each strip, about three being used, is well caulked before placing in the next one, the remainder of the space being filled with molten lead and staved as before described.

All pipes in connection with rams should be laid not less than 2 ft. below the ground surface

so as to be beyond the reach of frost. Running water does not freeze to the same extent as that which is still; but as rams sometimes stop for the want of attention, the water in the pipes will then freeze during cold weather, and this causes some trouble, especially when a mansion or other premises depend upon the water thus supplied.

Although usually considered as being necessary to fix the drive pipe with an even slope from the reservoir, or drive tank, to the ram, the latter will work very well if the pipe is laid with a gentle slope, so that all air can escape out of

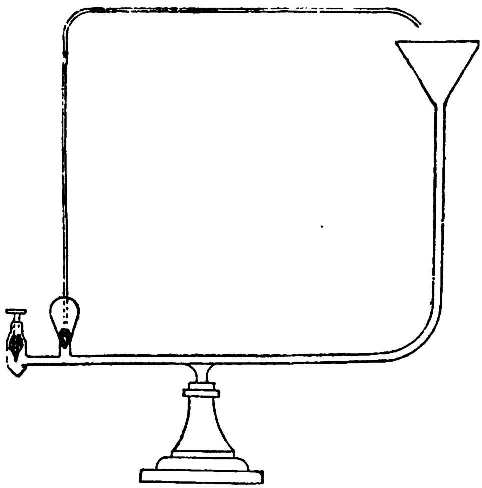

FIG. 9.

the inlet end, for a distance and then drop suddenly, or drop suddenly and then have a gentle slope.

A glass model of a working ram,* which was supplied to the writer by Messrs. Baird and Tatlock, of London and Glasgow, is shown by Fig. 9. Although having the appearance of

* This model cost only 4s., and is very useful for lecturing purposes.

a toy, it works very well indeed, and being made of glass, the action of the valves can be clearly seen. It will be noticed that the drive pipe is partly vertical and partly horizontal.

A small size ram, supplied by Mr. James Keith, A.M.I.C.E., for demonstrating and experimenting purposes, is fitted up at the Regent-street Polytechnic, as shown by Fig. 10. The feed or drive tank Z is a round lead cistern fixed on a shelf about 6 ft. from the floor. As shown by the figure the drive pipe is fixed to a wall and has an even fall the whole distance, but had

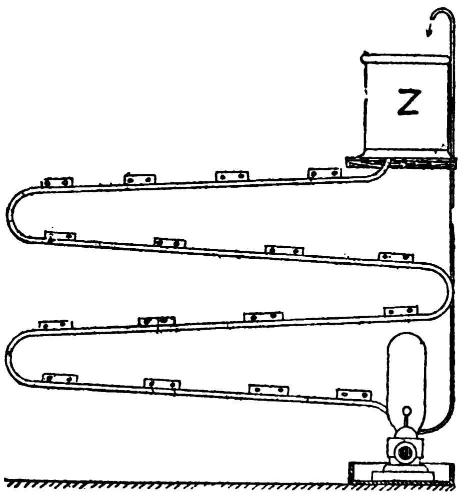

FIG. 10.

to be carried backwards and forwards for getting the necessary length, as space would not admit of its being in a straight line. And this ram raises water to a height of over 100 ft., as registered on a pressure gauge, thus showing that the bends in the drive pipe have no obstructive influence on the working.

Fig. 11 is a sketch of a ram made by the plumbing students for an Industrial Exhibition

at the Polytechnic. The whole is made of lead excepting the delivery valve inside the air vessel at A, and the "dash" or working valve at B. The ram was worked from a small lead cistern C filled by means of a ball cock from a main, and the drive pipe was wound round the cistern pedestal, as shown in the sketch. This crudely made ram, with a working head of 5 ft., raised water to a height of 50 ft., and it is doubtful if better results could have been ob-

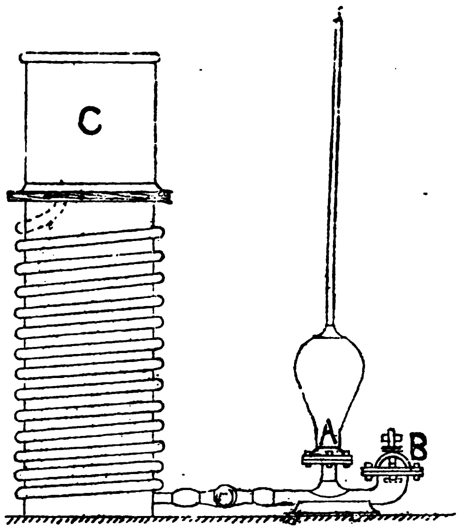

FIG. 11.

tained if the drive pipe had been fixed perfectly straight with a gentle slope to the ram.

These examples tend to prove that the drive pipe can be fixed zigzag when a straight line cannot be obtained. But it is important that no bends should be made to a lesser radius than five times the diameter, as shown by Fig. 12, in which D represents the diameter of the pipe. For the size and length of the drive pipe the maker of the ram should always be consulted,

as he has an especial knowledge of the subject and will always be found ready to give advice to customers.

And such advice should always be followed,

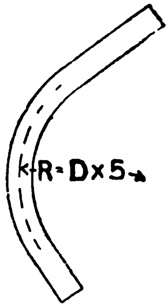

FIG. 12.

or failure may ensue or the best results not obtained.

Mr. Molesworth gives the rule for the necessary size :—

D = diameter of supply pipe in feet $= 1{\cdot}45 \sqrt{Q}$.

In which Q = quantity of supply in cubic feet per second.

To work an example, assume that the quantity of water available and necessary to work a ram of a given size is 3 cubic feet per minute. This is equal to $3 \div 60 = {\cdot}05$ cubic feet per second.

Then $\sqrt{{\cdot}05} = {\cdot}2236$.

And ${\cdot}2236 \times 1{\cdot}45 = {\cdot}32422$ foot, or 4 in. nearly.

Or, if only 1 cubic foot of water is available :

Then $1 \div 60 = 0{\cdot}0166$. $\sqrt{{\cdot}0166} = {\cdot}129$. And ${\cdot}129 \times 1{\cdot}45 = {\cdot}187 = 2\frac{1}{4}$ in. nearly.

For finding the length of the pipe the same authority gives the rule :—

L = length of supply pipe $= 2{\cdot}8$ H; where H = head of supply reservoir above escape valve in feet $= \frac{h}{20}$, and h = head of delivery above supply reservoir in feet.

If we assume that the water has to be raised to a hundred feet above the supply reservoir,

$$\text{Then } H = \frac{100}{20} = 5$$

And $L = 5 \times 2{\cdot}8 = 14$ ft.

This length would not answer at all in practice, and it would be much better to work to a ram maker's ordinary rule, for small size rams, and which is :—

Length of drive pipe = vertical height the water is to be raised.

But this rule cannot be accepted as being always suitable for application.

In all cases it is the weight of the water × into the height fallen that constitutes the power, and the quantity raised × into the vertical height raised + an allowance for friction, that constitutes the resistance to be overcome.

We may not succeed, but we can make an effort to find what should be the proper sizes and lengths for drive pipes for working rams. But there are several details which should be considered before attempting to arrive at a solution.

In the first place we must deal with the motive power, water. To be of practical use it must be at a higher level than the appliance it has to put into motion. To get it into that position a certain amount of energy has to be exercised to raise it. This energy may be derived from men, animals, or machinery, or from the wind and sun. If 100 galls. of water, which weighs 1,000 lbs., has to be raised to a height of 100 ft., then 1,000 × 100 = 100,000 foot-pounds of energy has to be exerted to raise the water to the given height. This energy is stored up in the water, is available for application to some useful purpose, and will again give out the same amount as was originally exerted.

If the water had to be raised by pumps or other artificial means for working a ram, there would be an enormous waste of power, as the machinery used would be more than sufficient for doing the work without the necessity of using a ram. In other words, roughly speaking, 1,000 foot-pounds of energy would sometimes

be exerted in raising water which would afterwards produce a useful effect of only 100 foot-pounds.

In the case of hydraulic machinery, such as lifts, hoists, presses, &c., and a natural head is not available, an artificial one can be created by pumping the water into a high reservoir or water tower, or into mains to which accumulators are attached. In these cases energy is exerted by the pumping machinery and stored in the raised water, to be afterwards given off intermittently as desired.

With a natural supply of water in a raised position, the energy has been developed by the sun or other natural influences, and is stored just the same as if it had been raised by machinery. And the head or height may be several feet or only a few inches.

For the above reasons a hydraulic ram is never used excepting where a sufficient quantity of water to work it is raised by natural means.

In utilising this energy a great deal of useful effect is apparently lost and wasted. But there is no such thing in Nature as waste. It is only that we fail to obtain the whole of the power or useful effect and apply it in the desired direction. The water is not wasted; and the power which was not utilised by the ram is still fulfilling natural laws by which the water flows to other and lower positions, fulfilling its mission in many directions, either in rivers, lakes, pools, seas; feeding vegetation, dissolving earths and rocks, or returning to the skies by evaporation to again start on its journey in a continual circle.

We frequently speak of loss of power by friction, and in the lectures on pumps* a considerable allowance was made for this. But the power is not lost, it simply fails to do all that is required in a desired direction. In machinery, the working parts are worn away by friction; and even that of the surrounding air detracts from the applied power. In machinery, all surfaces that rub together are made as smooth as possible, and lubricants are used to reduce the friction. Water-pipes are made as

* Pumps, their Principles and Construction. 8vo. B. T. Batsford, 1898.

smooth inside as possible to reduce the friction of the passing water which retards the velocity.

And yet without friction between bodies our mode of existence would be entirely different. We could not masticate our food, and our bodies would lose their natural heat; locomotion would be difficult, and vehicular traffic an impossibility. An engine could not pull or haul a train, and breaks would be useless for stopping one when in motion. Buildings could not stand, water streams would become torrents, and the surface of the earth entirely changed. Whichever way we turn we find that this influence has an important bearing. Engineers cannot do away with it, and many of the problems of their profession are to reduce it to the lowest degree in some cases and increase its influence in others.

When water is flowing through pipes that are rough inside, an allowance has to be made for reduction of velocity by rubbing against the sides, and larger pipes used than would be necessary if there were no friction. And this applies to drive-pipes to rams as well as to other pipes, either for water, air, steam, or other matters, which are enclosed or directed by the pipes in the course intended for them to take.

It has already been stated that a portion of the energy of falling water is wasted, or apparently not utilised in rams. In reality the waste is a necessity to the proper working. The action of a ram being intermittent, the beats of the valve vary according to the size of the machine, the head of the drive tank and the head of delivery, from 15 to 80 or 90 per minute. As soon as the dash valve has closed there is a slight recoil of the water in the drive-pipe, and the valve, by its weight and the backward momentum of the water, reopens and remains so for a fraction of a second until the velocity is again sufficient to suddenly close the valve. From this we glean that the so-called waste is actually a necessity.

Referring to our example of 100,000 foot-pounds of energy being stored at a height of 100 ft., the same amount will be given off

again, whether it comes down in one mass or is allowed to fall drip by drip. In the former case it is expended all at once, and in the latter it is spread over a considerable period of time.

Assuming that Fig. 13 is a lever balanced on a fulcrum, and at one end a weight, E, of 10 lbs. is placed. If a weight of 1 lb., or 1 lb. of water in a compact body, was allowed to fall from a height of 10 ft. on to the other end of the lever,

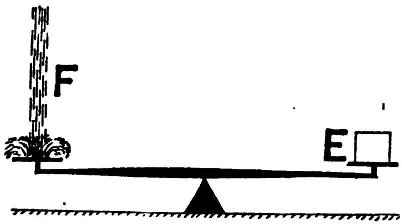

FIG. 13.

at F, it would balance E, but by adding to the weight of the falling body, or increasing the distance fallen, E would be raised, and at a speed proportionate to the increase on F.

If E was a body of water in a tube and the lever had a piston on the end which fitted the bottom end of the tube, the piston would push up the water inside provided the power at the other end was sufficient to do so. And this power may be exercised by a large body falling from a low height, or a small body falling from a great height.

But no levers are used in a hydraulic ram, and the power is exerted without the aid of any mechanical appliances beyond the valves which were mentioned when describing the construction.

Taking another illustration; let G, Fig. 14, represent a piston fitting in a tube constructed as shown, with a valve opening upwards at H, the whole being filled with water. If a weight was placed on the top of G, the water would be pushed up the pipe I, to a height which would balance the weight, and the two would be in a state of equilibrium.

But if the weight was raised some little distance and allowed to fall on G, the water would be driven up I to a height equal to the weight × into the distance fallen. If there were no valve at H the water would return to its first level by pushing up G and the weight resting upon it.

When the weight was allowed to fall on G, the contents of the apparatus were motionless,

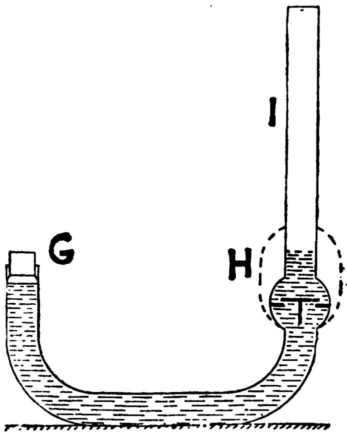

FIG. 14.

or in a state of inertia. A considerable portion of the energy of the falling weight was absorbed in overcoming the inertia, also by friction of the piston and water, and by the sides of the vessel in offering resistance to being broken.

Between the impact of the falling weight and the time that motion is imparted to the water an interval of time elapses. This is so very short that we cannot measure it, neither can we see it, and can only say that we feel it is so.

If an air vessel, as shown by dotted lines, Fig. 14, was fixed, the inertia and friction of the water in the body only has to be overcome, as the air in the vessel is compressed into a smaller space and absorbs some of the imparted

energy, instead of its being transmitted directly to the water in I.

The energy absorbed by the air is then slowly exercised, by the latter returning to its original density, in raising the water in I at a lower rate of speed than is given to the water in the body.

In the hydraulic ram the above piston, utilised for illustrating a principle, is water, and the falling weight is a body of falling or running water.

The force of running water in a drive pipe has to be calculated in a manner quite different to a problem in which the discharge from a pipe under a given head is sought.

In the first place the motion may be described as "stop and start." When the dash valve opens it does so at about the same speed as the water behind it when its motion is reversed.

The backward motion is small, but plainly discernable at the entry end of the drive pipe. If there were no backward motion the valve would not open. The weight of the valve alone is not sufficient, and it will remain closed for an indefinite time if held shut until all motion in the water has ceased.

As soon as the backward momentum of the water has been overcome, by the pressure from the drive tank, a forward motion takes place, very slowly at first, but gradually increasing in speed. But the highest velocity due to the head is not attained. As soon as sufficient speed has been attained to dash the valve onto its seating, the motion is again reversed and the whole proceeding repeated.

The greater the head, or height, of the feed tank the greater the power of the flowing water in the pipe and subsequent shock of the dash valve, which shock also acts on the body pipe and the underside of the delivery valve, which is pushed open and water forced through into the air vessel.

With great heads shorter drive pipes are necessary for doing the same amount of work. As an example, assume W represents weight of water, H its head, and R results.

Then $R = H \times W$.
If $H = 10$ and $W = 10$,
Then $R = 10 \times 10 = 100$.
If $H = 5$ and $W = 20$,
Then $R = 5 \times 20 = 100$ the same as before.
And so on for other variations of the factors. From this we learn that with low heads long drive pipes must be used.

Increasing the size or diameter of the pipes does not increase the working capacity of the ram, as the latter, including the dash-valve, has to be enlarged in proportion, or the force of the shock will be spread over a larger area of surface, both on the valve and inside the body pipe.

With a small size drive-pipe of a good length, and a proportionate size dash-valve, the same quantity of water moving in a body would strike on a smaller surface with increased results.

Rods of iron may be taken to illustrate this. Assuming three rods each weighing 10lbs. If one was 1 in. in diameter and fell endways a certain distance onto a piece of soft metal it would not indent the latter so much as a rod which was ½in. in diameter, and the latter would have less effect than one which was ¼in. in diameter and which fell the same distance. The smaller rods in each case being increased in length to make up the weight to 10 lbs.

The writer has carried out a number of experiments on hydraulic rams and some of these will be found interesting, although not always conclusive.

On looking over old pocket-books and the notes referring to Hydraulic Rams the writer cannot find anything that is of real use to students. Although many old appliances have been repaired or adjusted and new ones fixed by, or under his direction, his notes refer chiefly to the actual results obtained, coupled with statements as to lengths and sizes of drive pipes, and the quantity of water delivered and the height to which raised. But the quantity used and some other details are wanting.

In the early part of 1895 he began experimenting with the ram, shown by Fig. 10, and

although the results were carefully tabulated, he now finds with later experiences, that they are of little value.

So that the experiments could be conducted

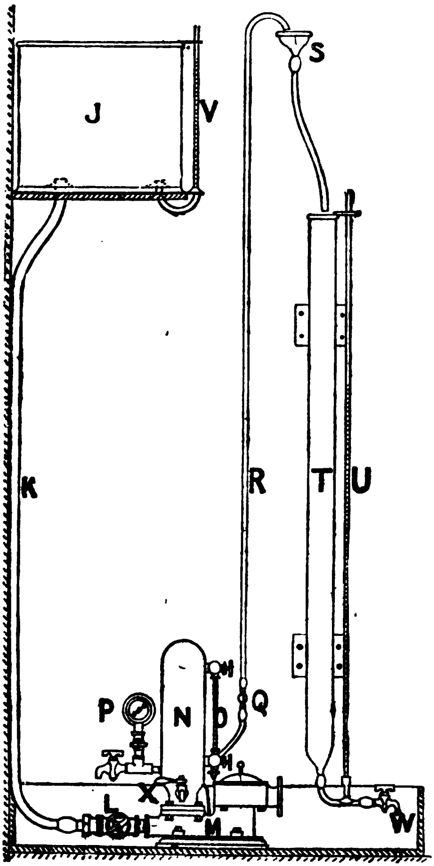

FIG. 15.

on better lines, he has had a few alterations made and additional appliances added. These

are shown by Fig. 15. In the illustration J is the feed tank; K, a 1 in. drive pipe 7 ft. 10 in. long with four springs (or long easy bends); L, a clear way, or gate valve; M, the body of the ram; N, the air vessel; O, a glass water gauge for showing the height of the water or degree of air compression inside the air vessel; P, a pressure gauge for showing the height to which the water is being raised; Q, a stop-cock on the delivery pipe, which is partially closed until the pressure gauge registers the height the water would be delivered if the pipe, R, was continued upwards. The latter pipe empties into a funnel, S, which discharges into a measuring chamber, T, having a graduated glass tube, U, by which the quantity of water raised in a measured time can be seen at a glance. A similar tube, V, is fixed outside the drive tank for showing the quantity used; W is an emptying cock for the measuring chamber, and X is a similar cock for the ram air vessel.

The sizes of the drive 1 in., and the delivery pipe ½ in., were governed by those of the connections which were supplied with the ram.

The tank holds 30·42 gallons, measured above the end of the drive pipe, and is 18½ in. deep. The working head when the tank is full is 8 ft. 1½ in., and when half empty 7 ft. 4 in. above the centre of the inlet to the body of the ram. As in practice it is found that in some cases the level of the water in the drive tank varies a little, some of the experiments were made with a measured quantity which had varying heads, giving a mean of 7 ft. 4 in. above the ram.

After making several preliminary experiments it was decided to divide the series into sections, some being worked under the mean given above, and others with a constant head by keeping the tank filled by means of a ball-valve.

Other variations were made by starting with an empty air vessel and others with it charged with water equal to the height of the delivery, as shown by the gauge. Others, again, were made with, in sporting phraseology, a "flying

start." Some of the tests were with the long drive pipe shown by Fig. 10, and others with the short pipe in Fig. 15.

The first, or preliminary test, was to find how long each pipe took to empty the tank when disconnected from the ram. With the short pipe, as Fig. 15, plugged at the cistern end, it took 1 min. 13 secs., but when plugged at the outlet end it took 5 secs. less. When plugged in the cistern and connected to the ram, the dash valve of which was held down, it took 2 min. 20 secs. to empty the tank.

With the long pipe, shown by Fig. 10, the tank emptied in 3 mins. 41 secs. when plugged at the upper end, but when plugged at the outlet, so that the pipe was full of water at starting, the time was 3 mins. 30 secs. When run through the ram without doing duty 4 mins. 10 secs. were occupied in emptying the tank.

The length of the latter pipe is 60ft. 4in. and it has 9 bends of about 90 degs. each, made to radii of about 4in.

The inlet ends of the pipes were slightly opened with a tan-pin, and the inside arris taken off to reduce the friction of entry as much as possible.

To compare the relative velocities of discharge of the short and long pipes :—

With the short pipe, which emptied the tank in 1 minute 13 seconds, the

$$\text{Velocity} = \frac{30{\cdot}42 \text{ gallons}}{{\cdot}034 \times 73 \text{ seconds}} = 12{\cdot}25 \text{ lineal feet}$$

or ·416 gallons per second.

With the long pipe which emptied the tank in 3 minutes 41 seconds the

$$\text{Velocity} = \frac{30{\cdot}42 \text{ gallons}}{{\cdot}034 \times 221 \text{ seconds}} = 4 \text{ feet}$$

or ·137 gallons per second.

From these calculations we learn that with the pipe which is nearly eight times longer than the other, the velocity of discharge is decreased to about one-third.

The short pipe holds ${\cdot}034 \times 7\frac{10}{12} = {\cdot}266$ galls. or

2·66 lbs. which × 12·25 ft. velocity = 32·58 ft.-pounds of flow-energy per second.

The long pipe holds ·034 × 60⅓ = 2·05 gals., or 20·5 lbs. And this × 4 ft. velocity = 82 ft.-pounds of flow-energy per second, or about 2½ times that of the short pipe.

We may here break the continuity of our subject for a brief time to compare the above velocities of discharge with those found by the rules for falling bodies.

With the short pipe giving a velocity of 12·25 per second.

The rule for finding the height necessary to give that velocity is $\left(\frac{\text{velocity}}{8}\right)^2$

Then $\left(\frac{12{\cdot}5}{8}\right)^2 = 2{\cdot}43$ ft. the head or height necessary to give the velocity.

But as the actual height was a mean of 7·33 ft. we have 7·33—2·43 = 4·9, or say 5 ft. of head which was absorbed by friction of water in the pipes, and at entry, and by change of direction by bends.

For the long pipe :—

$\left(\frac{4}{8}\right)^2 = {\cdot}25$ ft. of head to give the velocity.

And 7·33—·25 = 7·08 ft. of head absorbed by friction, &c., as before.

Box's rule for finding discharge from pipes, allowing for friction only in the pipe, and not taking into consideration change of direction by bends and friction of entry is :—

$$G = \sqrt{\left(\frac{(3d)^5 \times H}{L}\right)}$$

In which G = gallons per minute.
d = diameter of pipe in inches.
L = length in yards.
H = head of water in feet.

Then for the short pipe we have

$$G = \sqrt{\left(\frac{(3 \times 1)^5 \times 7{\cdot}33}{2{\cdot}36}\right)} = 27{\cdot}47 \text{ per minute.}$$

And $\frac{27 \cdot 47}{60} = \cdot 458$ nearly per second compared with ·4165 gallons found by experiment. The difference, or, ·458—·4165=·0415 gallon is caused by friction of entry and bends.

For the long pipe :—

$$G = \sqrt{\left(\frac{(3 \times 1)^5 \times 7 \cdot 33}{20 \cdot 1}\right)} = 9 \cdot 41 \text{ per minute,}$$

and $\frac{9 \cdot 41}{60} = \cdot 157$ nearly per second compared with ·136 as found by experiment. Here, too, the loss of ·157—·136=·021 gallon is occasioned by friction of entry and bends.

The entering ends and bends were made so as to retard the flow of water as little as possible, but our calculations show there is still a loss caused by them. We have also found that the friction in the pipes has an enormous influence in retarding the velocity of discharge, and must always be taken into account in hydraulic problems.

The results of several practical experiments with a hydraulic ram have been tabulated, and we will now deal with them.

The experiments gave such very peculiar results that it was found necessary to check them as far as possible. In the first place the readings on the pressure gauge were compared with the height of water, or degree of air compression, in the air vessel as seen in the gauge glass, to show the height to which the water was being raised by the ram.

To do this a drawing was made as shown by Fig. 16. The air vessel was drawn and horizontal lines made at the levels the water would be when under pressures varying from one to five atmospheres above the normal. These lines were then projected onto a diagram and the compression curve found.

The glass water gauge was then divided into inches, from the bottom upwards, and horizontal projections drawn as shown by dotted lines. On the bottom of the diagram is marked the pounds pressure per square inch exerted by the

water in the rising pipe from the ram, and beneath that the head, or height in feet to which the water is being raised, and which exercises the pressure marked above it.

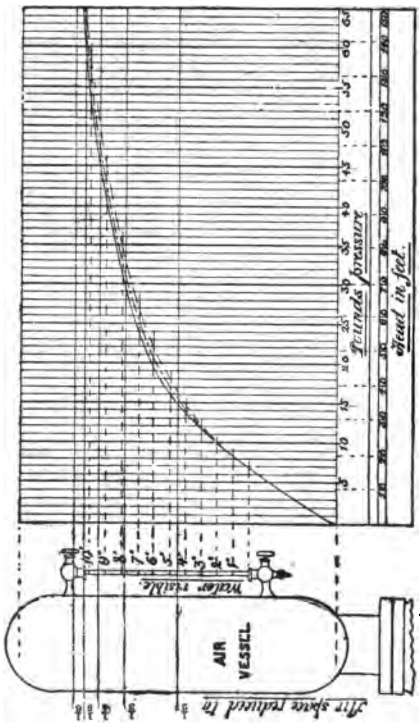

Fig. 16.

The lower, or dotted, curved line is deduced from the readings of the pressure gauge. A difference is found to exist, and this will be better understood by the following table of results of a series of five experiments.

EXPERIMENT I.

With varying head on drive-pipe which was 7 ft. 10 in. long.

Tims of test in minutes.	Average head on drive in feet.	Beats of dash valve per minute.	Pressure gauge in lbs.	Glass Gauge in inches.
$1\frac{1}{2}$	7 ft.	148	2·5	Not visible
,,	,,	148	5·0	,,
,,	,,	148	8·0	$\frac{3}{4}$
,,	,,	132	10·0	2
,,	,,	113	17·0	$4\frac{1}{2}$

EXPERIMENT II.

The same as last, but with a constant head of 7 ft. 4 in.

Time of test in minutes.	Head on drive-pipe in feet.	Beats of dash valve per minute.	Pressure gauge in lbs	Glass gauge in inches.
$1\frac{1}{2}$	7ft. 4in.	110	18·0	$4\frac{7}{8}$
,,	,,	110	22·0	$5\frac{3}{4}$
,,	,,	110	28·0	7
,,	,,	110	40·0	$8\frac{1}{2}$
,,	,,	104	53·0	$9\frac{5}{8}$

By comparing the pressure gauge readings with those on the glass gauge on the air vessel, we find a considerable difference between the computed heights to which the water is being raised. See the following table of comparison.

Table of comparison between the height the water is being raised as shown by the pressure and glass gauges respectively as found from the diagram.

Pressure Gauge.		Glass Gauge.		Difference.	
Lbs.	Equivalent in ft.	Reduced to lbs.	Equivalent in ft.	lbs.	Equivalent in ft.
2·5	5·76	—	—	—	—
5·0	11·45	—	—	—	—
8·0	18·0	8·0	18·0	0·0	0·0
10·0	23·0	10·0	23·0	0·0	0·0
17·0	39·0	15·0	34·5	2·0	4·5
18·0	41·45	16·0	36·8	2·0	4·65
22·0	50·6	19·5	44·9	2·5	5·7
28·0	64·5	24·5	56·4	3·5	8·7
40·0	92·1	35·5	81·8	4·5	10·3
53·0	122·1	46·5	107·1	6·5	15·0

We learn from this comparison that up to a certain point the two gauges agree, but beyond that a difference occurs. The pressure gauge may have varied a little in correctness between high and low pressures, or a slight inaccuracy may have occurred, owing to the smallness of the drawing, in the lines dividing the height of the air vessel to denote the various atmospheres of pressure.

But upon referring to the diagram the differences appear to be considerably reduced, and there is no doubt that another, or mean curve drawn between the two, as shown by the chain line, would very nearly approximate the actual facts of the case.

We also learn that any unavoidable inaccuracies when making notes on experiments mutually correct each other when plotted on paper ruled in squares or otherwise divided by lines.

The diagram, Fig. 16, will be used for showing the heights the water is being raised by the ram when giving the results of future experiments.

We may pass over a large number that have been made and deal only with those necessary for our purpose, and which are as nearly as possible, that can be found by the apparatus at our disposal, the results which would be

obtained in actual practice. Our primary object being to compare the difference between the duty performed by the short and long drive pipes.

The following tabulated results may now be considered.

Experiment III.

With the short drive pipe and with a flying start, that is, the records were not taken until the pressure gauge stood steady. Each test was timed to four minutes.

Water gauge in inches.	Pressure in lbs.	Equivalent in feet.	Gallons raised.	Gallons used.	Gallons wasted.	Dash valve beats per minute.	Head on drive-pipe in feet, average.	Efficiency or per cent. of duty.
0	4·0	9·2	5·33	13·33	8·0	150	7·00	53
½	7·5	17·2	5·66	16·00	10·34	150	"	86
3¼	12·5	28·8	1·66	15·75	14·9	118	"	43
6½	22·5	51·8	·6	15·5	14·9	114	"	28
7½	28·0	64·5	·4	16·0	15·6	114	"	23
7¾	29·0	66·8	·125	11·0	10·875	112	"	10
8¼	34·0	78·3	·128	11·75	11·622	110	"	12

EXPERIMENT IV.

All as last but with the long drive pipe.

Water gauge in inches.	Pressure in lbs.	Equivalent in feet.	Gallons raised.	Gallons used.	Gallons wasted.	Dash valve beats per minute.	Head on drive-pipe in feet, average.	Efficiency or per cent. of duty.
0	4·0	9·2	5·137	14·136	9·0	28	7·00	47
1¼	8·5	19·5	2·9	14·75	11·85	33	"	54
3	12·0	27·6	1·8	14·0	12·2	36	"	50
5	17·0	39·1	1·0	14·0	13·0	36	"	40
6	20·5	47·2	·9	13·75	12·85	37	"	44
6¾	24·0	55·3	·85	13·75	12·9	37	"	48
7¼	26·5	61·0	·75	13·0	12·25	37	"	50
8½	37·0	85·2	·575	12·5	11·925	36	"	56
9⅛	47·5	109·4	·325	11·5	11·175	36	"	43
9¾	53·0	122·1	·25	11·25	11·0	36	"	38

The results as tabulated in the foregoing are most extraordinary. Taking table No. 3, the two first items show the same number of valve beats as taking place in the same space of time, but more water was used and more raised to a greater height, thus showing a higher rate of duty of one over the other.

In these two experiments the dash valve opened only a very short distance, but as the height of delivery was increased, the stroke lengthened, and when beating 112 and 110 opened to the full extent. But the force of the falling water was not sufficient to raise any considerable quantity when the height of the delivery was increased, as shown by the last two items.

The table No. 4 shows a much more even series of results, both with regard to the valve beats, quantity used, and also raised. With a long drive pipe a considerable increase is found in the percentage of duty performed, and this is shown by a comparison of the tables.

During these experiments great interest was taken in the action of the water in the air vessel as seen in the glass gauge. With the short drive pipe in use the water appeared as if "jerked" into the vessel, but with the long pipe it appeared as if "pushed" upwards, if a difference in the two terms of expression can be understood as applying to the action. In other words, at the same instant that the dash valve closed, with the short drive pipe, water was quickly forced into the vessel, but with the long pipe the water continued to rise for a short time afterwards, as if the motive force was more sustained.

This was further illustrated by holding the end of the spindle of the dash valve with the fingers. When the short pipe was in use very little effort was necessary for holding the valve tight up to its seating, but when the long pipe was on a very strong pulling power was found to be exerted after the stroke, and this was repeated in about 1 to 2 seconds afterwards. In other words, in the first case the ram's action could be immediately stopped, and in the other the valve had to be held for some little time until the, what may be termed, oscillating motion of the water in the drive pipe was arrested.

Another detail suggested itself during these experiments which would probably account for a considerable portion of the reduction in the percentage of duty when water is being raised

to great heights. If we assume that air is an elastic, and water a solid, fluid, we can then understand that when the vessel is filled with air water forced through the delivery valve meets with very little resistance as the air is easily compressed to make room for it. But when nearly filled with water, the air being tightly packed in the upper portion of the vessel, any incoming water is resisted by the column of that above the delivery valve, which has weight, and is also in a state of inertia, so that a portion of the force is expended in lifting the water in the air vessel, and also in starting it from a position of rest.

The next experiments were with a measured quantity, 28 gals., of water and a varying head averaging 7·5 feet on the drive pipe.

EXPERIMENT V.

With the short drive pipe.

Duration of test.		Height raised in feet.	Gallons raised.	Beats of dash valve per minute.	Efficiency or per cent. of duty.
Mts.	Secs.				
7	10	25	5·2	145	62
7	10	36	3·2	131	53
8	30	64	1·9	108	36
9	0	70	1·1	110	36
9	15	92	0·425	108	18

EXPERIMENT VI.

With the long drive pipe.

Duration of test.		Height raised in feet.	Gallons raised.	Beats of dash valve per minute.	Efficiency or per cent. of duty.
Mts.	Secs.				
9	0	25	5·66	35	67
9	8	36	3·7	35	63
9	10	64	2·05	36	62
9	25	87	1·4	37	58
10	45	115	0·85	34	46

Before making the above experiments a slight alteration was made to the washers on the dash valve, with the result that a more even series was obtained. It may be added that the whole were carried out with the same ram and pipes, and no alterations were made to suit the varying heights to which the water was raised. The working conditions were the same throughout, with the exception of the length of the drive pipe and adjustment of the stop cock on the delivery pipe.

The previous remarks as to the importance of a long, in distinction to a short, drive pipe, are again emphasised by the above practical results. The actual working length of the latter pipe can be approximately found, but that we will explain presently.

For the benefit of the junior students we may here explain how the percentage of duty, given in the last column of the above tables, is calculated.

If we assume that a man can lift, between his legs when standing, a weight of 200 lbs., the whole of his power is usefully exerted and he gets a percentage of duty of 100, or cent. per cent.

But if he had to drag the same weight on a road, his pulling power, if limited to 200 lbs., would not move the weight, as a part of his strength would be absorbed by friction between the road and weight.

If, by gradually reducing the weight until he could drag it, eventually he found he could move only 150 lbs., then the percentage of useful effect would be found by simple proportion, or rule of three, as follows :—

As 200 lbs. : 100 : : 150 lbs. : the answer.

Or stated thus :—

$$\frac{100 \times 150}{200} = 75 \text{ or } 75 \text{ per cent.}$$

The power which works a ram is the quantity of water used multiplied into the height from which it falls or flows. Example taken from the last table :—28 gals. are used and they fall 7·5ft., and $28 \times 7{\cdot}5 = 210$ foot-gallons of flow-energy or

power. The useful effect was 5·66 gals. raised to a height of 25 ft., and $5·66 \times 25 = 141·5$ foot-gallons. By dividing the useful effect by the power exerted we get

$$\frac{141·5}{210} = ·67 \text{ or } \frac{67}{100} \text{ or 67 per cent.}$$

Stated concisely the problem would be

$$\frac{5·66 \times 25}{28 \times 7·5} = ·67$$

or 67 parts out of every hundred of power usefully exerted, the remainder being absorbed by, or contained in, the machine and the water inside.

The remaining 33 parts are not by any means wasted, but are doing duty to the utmost extent.

A portion is required for lifting and suddenly closing the dash valve, which has considerable weight. Another portion is necessary for lifting the delivery valve, inside the air vessel, and the water above it, and also in still further compressing the air in the upper part, this again being transmitted to the water in the delivery pipe to keep it in motion between the beats of the dash valve. A further portion of the 33 parts is absorbed by friction of the water in the pipes, and a considerable part is required to reverse the direction in which the water is travelling in the drive pipe. If this water does not recoil the dash valve will not open, but will be held up to its seating, and thus stop the action of the ram.

And, again, the further the water is driven back the greater the force with which it returns. With a short drive pipe the water can return but a short distance, so that the intervals between the change of direction of flow are very small. Thus we find from the practical experiments that there is a great difference in the number of strokes per minute between the two pipes which were used. We also find that there is more waste with the short pipe. This we should expect, as the dash valve opens three to four more times than with the long drive pipe.

The experiments have also shown that with the short drive pipe the increase in height to which the water is being raised results in a de-

crease in the number of beats per minute of the dash valve, and also in the quantity of water raised. With the long drive pipe the results are more even.

We will now compare the working power of a ram with the useful effect, and make an approximate allowance for friction and other influences which detract from the theoretical results. We had better first have the rules by which to work and then apply them to our purpose.

So as to state them concisely and avoid long written descriptions, we will assume that :—

Q = quantity of water used.
q = quantity of water raised.
H = head on drive pipe.
h = height to which delivered.

$$\text{Then } Q = \frac{q \times h}{H}$$

$$H = \frac{q \times h}{Q}$$

$$q = \frac{Q \times H}{h}$$

$$h = \frac{Q \times H}{q}$$

To explain the first formula in words :—

The quantity of water necessary to work a ram is equal to the quantity raised multiplied by the height to which raised, and divided by the head on the drive pipe. The height and head being in feet, and the quantities used and delivered being in gallons.

EXAMPLE I.

Assuming that we want to find the quantity of water necessary to raise 10 gals. to a height of 50 ft., the surface of the water in the drive tank being 6 ft. above the ram.

$$\text{Then } Q = \frac{10 \times 50}{6} = 83{\cdot}3 \text{ gallons.}$$

If, for rough approximation, we allow ⅛ more

for friction and excess of power over work we have

$$83{\cdot}3+\frac{83{\cdot}3}{3}=111 \text{ gallons.}$$

as the actual quantity necessary.

EXAMPLE II.—To find H.

$$\begin{aligned} \text{If } Q &= 50 \\ q &= 6 \\ h &= 30 \end{aligned}$$

$$\text{Then } H=\frac{6\times 30}{50}=3{\cdot}6$$

to which add $\frac{1}{3}$=4·8 feet head on drive pipe.

EXAMPLE III.—To find q.

$$\begin{aligned} \text{When } Q &= 40 \\ H &= 6 \\ h &= 60 \end{aligned}$$

$$\text{Then } q=\frac{40\times 6}{60}=4 \text{ gals.}$$

from which should be deducted $\frac{1}{3}$rd.

And $4-\frac{4}{3}=2{\cdot}66$ gals. the actual quantity raised.

EXAMPLE IV.—To find h.

$$\begin{aligned} \text{When } Q &= 60 \\ H &= 10 \\ q &= 5 \end{aligned}$$

$$\text{Then } h=\frac{60\times 10}{5}=120 \text{ ft.}$$

from which deduct $\frac{1}{3}$ = 80 ft. the height to which the water would be raised.

In the above no time for doing the work is mentioned, and neither is it necessary, as that during which the power is being exerted equals the time in which the actual results are obtained.

In the foregoing random examples a constant of $\frac{1}{3}$rd was taken as an allowance for excess of power over load, &c., in all cases, but by studying the results in Experiment VI., the percentage of so-called loss is found to vary from 33 to 54, thus showing that our value would not apply

under all conditions with regard to quantity of water either used or raised, nor variations in height of feed or delivery.

If we take the results in Table VI., and deduct the lowest from the highest, we have 67—46= 21 difference in the percentage of useful effect. And if we deduct the lowest from the highest height raised we have 115—25=90 ft. And

$$\frac{90}{21}=4{\cdot}2.$$

From this we may assume that an approximate loss of 1 per cent. is due to every increase of 4·2 ft. in the height to which the water is raised when we take as our datum the results in Experiment VI.

We will now endeavour to find the necessary lengths of drive-pipes so that each of the experiments in Table VI. showed the same efficiency as the first one.

The pipe was 60 ft. long, and with varying conditions gave an efficiency of 67, 63, 62, 58, and 46 respectively. Although it is the quantity or weight of water that gives the impulse, we need not take that into our calculations, but simply deal with the length of pipe, as that represents the comparative proportion of water necessary to do the required work.

Then we proceed as follows, by ordinary rule of three.

As 63 per cent : 60 ft. : : 67 per cent : 63·8 ft. the length of drive-pipe necessary for gaining the same percentage of duty for the second as for the first in the table.

For the third experiment, by the same reasoning :—

$$\frac{60 \times 67}{62}=64{\cdot}8 \text{ ft.}$$

For the fourth experiment

$$\frac{60 \times 67}{58}=69{\cdot}3 \text{ ft.}$$

And for the last in the table

$$\frac{60 \times 67}{46}=87{\cdot}4 \text{ ft.}$$

By lengthening the drive-pipe there is an increase of friction of the inside water and the length of stroke is increased. The longer column of moving water would occupy more time in reversing the direction of its flow, resulting in slower beats of the dash valve. But the ultimate results would be about the same as worked out theoretically above.

When work or resistance is increased the power to overcome it must also be increased.

We have dealt with increase of power by lengthening the drive-pipe; we can also gain the same object by raising the height of the drive tank.

The height of the feed water surface was 7·5 ft. above the ram, and (from Table 6) raised a portion to a height of 25 ft. developing an efficiency of 67 per cent. By the same reasoning as was used for the drive-pipe length—

$$\frac{7{\cdot}5 \times 67}{63} = 7{\cdot}97 \text{ ft.}$$

the height the water should be for the second experiment.

For the third—

$$\frac{7{\cdot}5 \times 67}{62} = 8{\cdot}1 \text{ ft.}$$

For the fourth: —

$$\frac{7{\cdot}5 \times 67}{58} = 8{\cdot}66 \text{ ft.}$$

And for the last: —

$$\frac{7{\cdot}5 \times 67}{46} = 10{\cdot}9 \text{ ft.}$$

Referring again to our length of drive-pipes, our calculations were based on a ram capable of doing the work which was required. Other size rams could be used to give approximately the same results. But if they were larger then the drive-pipes could be shorter, but the diameters should be proportionate to the ram. In working out such problems the following table of capacities of pipes will be found useful.

TABLE OF CAPACITIES OF DIFFERENT SIZE PIPES.

Internal diameter of pipe in inches.	Contents in gallons per foot lineal.	Weight of water in lbs. per foot lineal.
¾	·019	·19
1	·034	·34
1¼	·053	·53
1½	·076	·76
2	·136	1.36
3	·306	3·06
4	·544	5·44
5	·852	8·52
6	1·224	12·24

If a pipe holds a given number of gallons, a larger one holding the same quantity is shorter in length.

Taking the pipe which was 87·4 ft. long. From the table we find a 1 in. pipe holds ·034 gals. per foot, and $·034 \times 87·4 = 2·9716$ gals.

An 1½ in. pipe to hold the same quantity

$$= \frac{2·9716}{·076} = 39 \text{ ft. long.}$$

With a ram constructed to work with 1½ in. pipe the latter length would enable it to raise as much water as the smaller ram worked with a 1 in. pipe, 87·4 ft. long, other conditions being equal.

To show this, assume 8 ft. head :—

Then $8 \times 1^2 \times ·034 \times 87·5 = 23·8$ ft.-gals. of flow energy.

And $8 \times 1·5^2 \times ·034 \times 39 = 23·86$ ft.-gals., or the same power as the other if the decimal fractions had been carried further in the calculations.

But the larger size pipe would not give the same results with the smaller ram for reasons that have been before explained.

The writer has recently had some correspondence with the makers of the experimental ram used by him, and they have given him a few results obtained by them in actual practice. These further emphasise previous remarks as to the value of long drive-pipes.

Their results are as follows :—

With an "A" or small-size ram fitted with 66 yards of 1 in. lead drive-pipe, 15 ft. fall, 2⅛ gals. supply per minute, 700 gals. were raised in 24 hours to a height of 65 ft. above the ram through 250 yards of ¾ in. pipe. This gives :

$$\frac{700 \times 63}{2\frac{1}{8} \times 60 \times 24 \times 15} = \cdot 9$$

or 90 per cent of effective duty.

With "B" size ram fitted with 50 yards of 2in. drive pipe, 6ft. fall, 6 gallons supply per minute, 700 gallons were raised per 24 hours, 63ft. above the ram through one mile of 2in. delivery pipe.

This ram gave :—

$$\frac{700 \times 65}{6 \times 60 \times 24 \times 6} = \cdot 85$$

or 85 per cent. of effective duty.

With a "C" size ram with 112ft. of 3in. pipe, 8ft. fall and 14,000 gallons supply per 24 hours, 2,000 gallons were raised 42ft. above the ram.

Then for this case we have :—

$$\frac{2000 \times 42}{14000 \times 8} = \cdot 75$$

or 75 per cent of effective duty.

The water supply to this latter ram was not entirely satisfactory and varied considerably. Eventually it became so reduced that it was found necessary to fix a smaller size dash valve when the per centage of effective duty rose to 81.

The makers also draw attention to the lengths of the above drive pipes which varied in length from two to three times the vertical height to which the water was raised. They also mention that it is difficult to formulate any rules for rams and that every case has to be considered separately.

Having so far given the principles upon which calculations are made, and explained that to do a certain amount of work the drive pipe must not be less than a given size and length, it now remains to explain that the other extreme must not be gone to.

If the drive pipe is too long the power is so much increased that, in the absence of adequate

resistance or work to be done, the ram is seriously injured by the excessive shock.

The writer had such a case in which the delivery valve inside the air vessel was constantly breaking, and every few days a new one was necessary. The drive pipe was 4in. in diameter and 300ft. long, and capable of raising a large quantity of water to a height of over 200ft. The actual height required was only about half that to a mansion about three-quarters of a mile distant.

By fixing a square head stop cock in the delivery pipe, near the ram, and closing it until

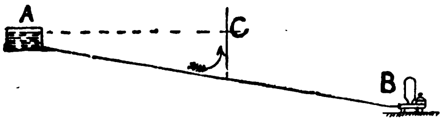

FIG. 17.

a temporary pressure gauge registered the desired resistance, the ram was made to work satisfactorily in so far as giving an ample supply of water without any of the working parts or valves breaking by the shock of the drive water.

Another case in which the drive pipe was 300 yards long and 6in. in diameter the pipes frequently burst, and it was found that ordinary cast-iron would not resist the shock of the water inside. To relieve this a stand pipe was fixed about midway between the ram and feed tank, so that a portion of the force of the moving water was spent in pushing a quantity up the stand pipe each time the dash-valve closed.

To explain this, assume Fig. 17 to be a sketch of the arrangements, the water flowing from the tank A to the ram B. Without the stand pipe, C, the whole of the force is expended on B. But with the stand pipe, when the dash-valve closes, a portion only of the force is expended on B and the remainder in pushing the water up C as shown by the bent arrow. Approximately about ⅓rd of the force of the moving water is thus taken off B. The stand-

pipe was continued above the level of the feed tank, otherwise water would have been forced out of the top end.

In both of the above cases there was a waste of power, and money was ill-spent, not only in the first cost, but in the additional outlay for disposing in a useless manner of the excess of force or power.

Neither should the feed tank be at too great a height above the ram, because of excessive shock having an injurious influence on the materials used for the ram and pipes.

There is a great difference of opinion as to the cause of the current of the drive water reversing when the dash-valve closes. By some it is held that water is elastic and rebounds much in the same manner as an indiarubber ball would. That this is not so is evidenced by breakages that take place in water-pipes by what is known as water-hammer. If water was elastic the loud noises made in service-pipes when a bib-cock is suddenly closed would not be heard, and an elastic medium, such as air confined in a chamber, would not be necessary for preventing it.

Another example is found in the philosophical appliances shown by Fig. 18, and known as a water-hammer. These are made of glass and are about half filled with water. The other half has the air exhausted, the remaining space being known as a vacuum. By holding them upright and smartly raising and then lowering them the water is jerked upwards, and on falling makes a noise as if two solid bodies had knocked together.

Or if held with the bulbs downwards until all the water has run into that end, and then suddenly reversed and held close to the ear, the water trickling into the straight tubes makes a noise similar to pebbles falling onto something hard. And this would not be so if water was elastic.

Neither would it be safe to assert that the materials of which the ram is made are sufficiently flexible to "give" with the force of the

water, and on returning to their original form push the water back.

If air was inside the body pipe the full force of the water would not be utilised, and a lesser quantity would be raised by the ram owing to the air acting as a spring buffer.

But as the water is driven back, and some

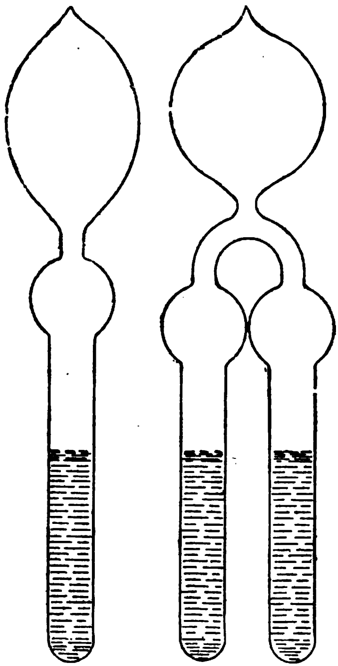

FIG. 18.

power is necessary to do this, it only remains to fall back upon the delivery valve inside the air vessel.

When making exact, or as nearly as possible, calculations on the duty done by pumps an allowance has to be made for what is known as "slip," or the small quantity of water that

returns into the suction-pipe when the sucker valve is in the act of closing. When the delivery valve inside the air vessel is in the act of closing a small quantity of water is pushed back into the body-pipe of the ram, and this, although small, is probably just sufficient to start a backward motion in the drive water.

It must not be forgotten that the weight of the dash-valve has also an influence in the same direction, and also the elastic seatings of the delivery valves.

Many makers have given the dash-valve a considerable amount of thought, and on searching through the patent office records a variety of forms are found to have been patented from time to time.

Fig. 19 is a sketch of a patented ram in which the dash-valve, shown by the dotted lines inside the body at D, is fixed on a pendulum E, with a counter-balance F. A modification of

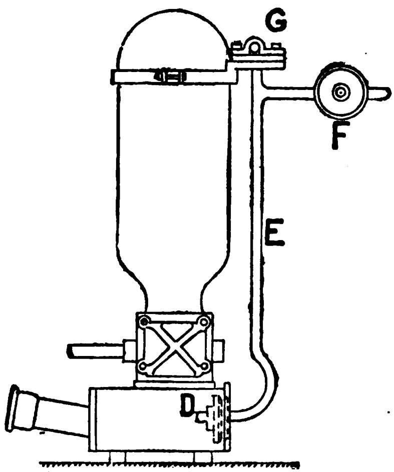

FIG. 19.

the same patent has a spring with adjusting screws at G, instead of the hinged joint and counterbalance. Either of these would have a

tendency to open the valve and push back the water.

Fig. 20 is a detail of another patent, in which the dash-valve has a rubber ring at H. When the valve dashes up against the seating, I, there is little doubt the "spring" of the rubber

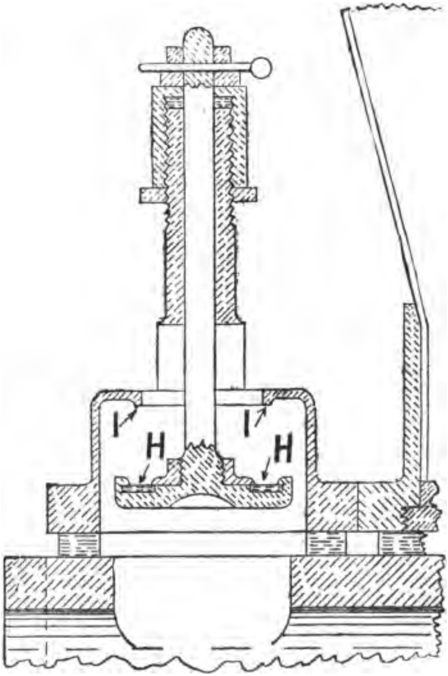

FIG. 20.

acts a part in causing the drive water to be reversed in its direction.

Another specialist has a patent for the ram shown by Fig. 21. For aiding the recoil of the drive water a small chamber J has a valve over the opening K in the body pipe. This valve fits tightly, but is free to slide up and

down. Over the valve is a spring and adjusting screw for pressing the valve downwards.

When the dash-valve closes by the momentum of the feed water part of the force is exerted in pushing some of the latter through the delivery valve L, and at the same instant of time the valve K is pushed upwards and compresses the spring. As soon as the full force of the feed water is expended the spring pushes the valve K down and causes the current of drive water to be reversed, when the whole of the action is repeated.

The same maker has other patents, in which what may be termed the seating of the dash-valve has a concave or hollow surface, and is perforated with several holes for the water to pass through. A short distance away from the

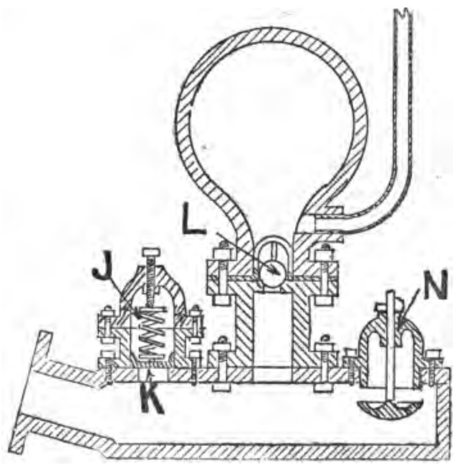

FIG. 21.

seating is an indiarubber band, in some cases, and discs in others, which is forced against the seating by the momentum of the water. The indiarubber is stretched in doing this, and on returning to its ordinary degree of tension causes a slight recoil in the direction of the flow of the drive water.

Another patented ram has a spring fixed outside the discharging outlet, so that the spindle of the dash-valve knocks against it. The spring acts similarly to a person's finger pressing on the spindle and thus pushes it down and reopens the valve. The use of this spring is claimed for another purpose but doubtless could be made to answer for that suggested.

An ordinary dash-valve is shown in section by Fig. 22. The outlet orifice has about the same diameter as the inlet to the body and the length of the stroke, which gives the opening between the valve and the seating, or the free waterway between them when open, is regulated by fixing washers on the spindle at M.

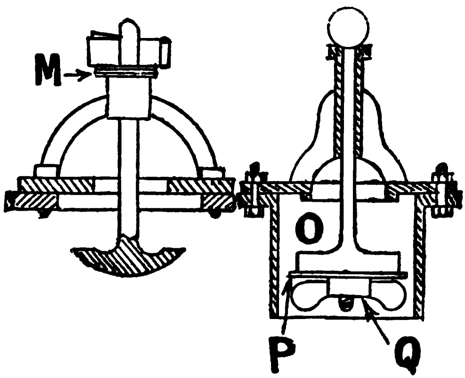

FIG. 22. FIG. 23.

The valve shown in Fig. 21 is an improvement on the last one as the spindle works more truly in the guide N. The valve can also be easily taken off for repairs or substituting a new one.

In Fig. 20, the dash-valve works in a cylinder, and doubtless economises the water, as very little can escape without doing duty.

Fig. 23 is an enlarged section of the dash-valve in the ram shown by Fig. 15. This also works in a cylinder O, and has a copper disc P, carefully fitted so that the whole of the force of

the water is utilised without unnecessary waste. The butterfly nut, Q, has the blades fixed obliquely, so that the passing water imparts a slight rotary motion to the valve and thus prevents the face of the latter, or the seating, being unevenly worn. The beats of this valve and the lengths of the strokes regulate themselves according to the power exerted, as was shown by the tabulated experimental results that we have dealt with.

Delivery valves are those fixed on the body of the ram at the bottom of the air vessel, and through which a portion of the water is pushed at each stroke of the dash-valve. Amongst the earliest made, and used by some makers at the present time, are those known as "spherical" valves, which consist of gun-metal balls with

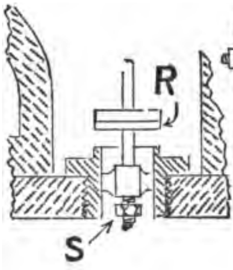

FIG. 24.

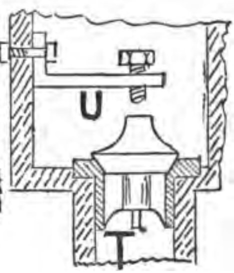

FIG. 25.

seatings, as shown at L, Fig. 21. This has a cage for preventing the ball rising too high or being dislodged from its position.

Fig. 24 is another kind which has an india-rubber seating at R, and a spindle with a guide bar and nut at S.

Another valve is shown by Fig. 25. This is a "ground-in" gun-metal valve T, with "feather guides" and a "stop" and regulating screw U, for preventing the valve rising too high or jumping out of its position.

The delivery valve to the patent ram, of which Fig. 20 is the dash-valve, is shown by Fig. 26. In the figure V V are perforations in a brass seating, and W is a rubber disc with

cap and spindle. The object being to get as large a waterway as possible without raising the valve too high, with the consequent lesser loss of water by "slip."

Another delivery valve, which forms a part of two or three patents, is shown by Fig. 27. This is simply a valve hinged on one side.

As a rule most makers have the delivery valves of a good size for reasons above given. In some cases the waterways are equal, and in others the diameters are only about half that of the drive-pipes.

With small size rams access to the delivery valves is obtained by unbolting and removing the air vessels, but with large rams having very

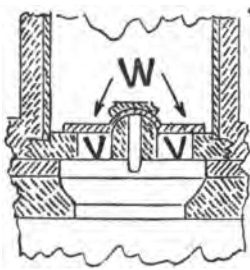

FIG. 26.

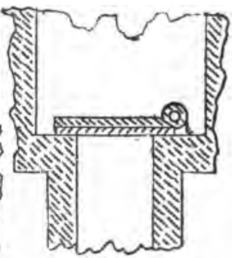

FIG. 27.

heavy air-vessels this would be inconvenient, and access-doors or removable side plates over openings are provided for the purpose.

With regard to the proper sizes of air-vessels the ordinary rule is, the capacity of the latter should be equal to the contents of the delivery pipe. But this is impracticable as one pipe may be 100 yards long and another a mile or upwards, so that each ram would require a special-sized chamber.

A better rule would be :—Contents of air-vessel should be equal to twice the contents of the delivery pipe whose length is equal to the vertical height to which the water is raised. An average being taken so that one size of vessel would be about right for each size of ram under varying conditions.

When an air-vessel loses its air by absorption by the water an enormous strain is brought to bear upon the ram, and its efficiency is lowered. Without air, and the vessel "water-logged," the whole of the water in the delivery pipe "stops and starts" with each pulsation of the working or dash-valve. Whereas with a properly charged air-vessel the water in the delivery is in motion the whole of the time the ram is working, and travels at only about one half the speed, with a consequent reduction of friction. When the water is motionless between the strokes a great deal of the applied power would be occupied in overcoming the inertia of the water in the delivery pipe and starting it into motion.

Not only is the ram robbed of a portion of its efficiency, but where the water is forced directly into a tank or cistern in an inhabited house, complaints have been made that each stroke of the ram was distinctly heard in the house, and prevented people sleeping at night.

In one case this was so serious that the writer, to sever the metallic connection of the iron pipe with the ram, had a piece of indiarubber tubing especially made for the purpose, and bound outside with wire to resist the internal pressure. This was fixed near the ram, a portion of the delivery pipe being removed for the purpose.

Although this reduced the noise considerably, it was still heard, and the conclusion was come to that water itself is a good conductor of sound.

Another complaint, in the same mansion, was the noise of the water trickling down the cistern overflow pipe which was fixed inside the house so as not to be affected by frost in the winter time. For these reasons the writer considers it inadvisable for a ram to deliver the water directly into a house, unless there is an isolated wing in which the cisterns and pipes can be fixed, and it should be sent into a reservoir or water tower from which it can gravitate or flow to the house or premises.

The loss of air out of the vessels is a troublesome problem, and a considerable amount of

thought has been given with the view to overcoming the difficulty.

One ram specialist has invented a substitute for the air vessel, which consists of a hollow cylinder with a solid end inverted in a second cylinder fixed over the delivery valve. The inverted cylinder is held down by springs and slides inside the other one, a special provision being made for the joint between the two to be watertight. At each pulsation of the dash valve

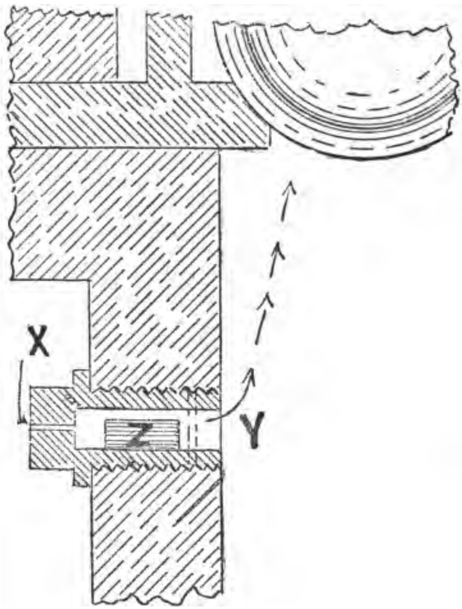

FIG. 28.

the water that is forced through the delivery valve causes the sliding cylinder to rise, the action of the springs then slowly forcing it down again and expelling the water into the delivery pipe.

For prevention of loss of air out of the vessels it has been suggested that sperm oil, glycerine

or other suitable liquid, poured into the vessel, would float on the surface of the water and prevent contact with the contained air, but the writer has no knowledge of the results, or if the water was rendered unfit for domestic purposes.

Another suggestion was to have the air vessel in two halves and bolt an indiarubber diaphragm between the flanges, so that the air and water were not in contact.

Many devices have been invented for keeping the necessary quantity of air in the vessel. One of the earliest was known as the "sniff"

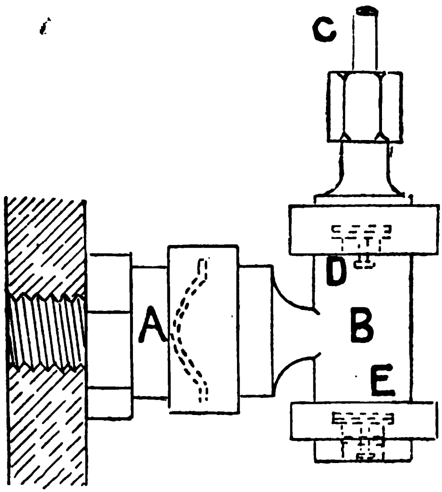

FIG. 29.

or "sniffle" — valve, sometimes called the "snorter." This is shown in section by Fig. 28, and is generally screwed into the side of the trunk leading from the body pipe to the air vessel just below the delivery valve. At X is a small hole about the size of a pin, Y being the end screwed into the trunk. The small piston Z is loose and free to slide to and fro, a stop pin being fitted as shown by the double dotted line.

When the dash-valve closes, the water that

forces open the delivery valve acts also on Z, and drives it towards the inlet X. When the water recoils the valve also is drawn back and a small quantity of air enters through the hole X, bubbles upwards at Y, as shown by the arrows, and is carried with the next rush of water through the delivery valve into the air vessel. And this is repeated at each beat of the working valve.

Fig. 29 is a side view illustrating the principles of another air valve. The screwed end is fixed in the ram body pipe, the end being open for the water to enter. When the dash-valve closes the water is forced against a flexible cup, shown by double dotted line at A, the air on the opposite side and in B being expelled through a valve at D and the pipe C, which is connected to the air vessel above the delivery valve. Another valve at E acts similar to the sucker valve of a pump. Air enters through this valve to fill the body B when the flexible diaphragm A is drawn back by the recoil of the drive water to the ram. By this arrangement a small quantity of air is pumped, or forced, into the chamber at each stroke of the dash-valve.

There are other, and patented, sniff valves which work similar to the last one, with the exception of having a piston with cupleather instead of the indiarubber, and a spring to aid the recoil of the water for drawing air through E into the chamber B. These are literally air pumps, but it is not necessary to illustrate them, as the principles are so very similar to those shown by Fig. 29. Hollow indiarubber balls have been proposed for placing in air vessels and air pumps for working by hand for recharging, but the writer has never seen these in actual use.

With regard to the proper sizes for the delivery pipes of rams it would be a difficult matter to lay down a hard and fast rule, and we cannot do better than use that for the delivery pipes of lift pumps, which is, that they should not be less than half the diameter of the barrel or, in the case of rams, of the drive pipe.

The following table about agrees with this,

and also some ram makers advice on the subject :—

Drive pipe.	Delivery pipe for short distances.	Delivery pipe for long distances.
1 inch.	3/8 inch.	1/2 inch.
1½ ,,	½ ,,	¾ ,,
2 ,,	¾ ,,	1 ,,
3 ,,	1¼ ,,	1½ ,,
4 ,,	1½ ,,	2 ,,
6 ,,	2½ ,,	3 ,,

For long distances, of ¼ mile and upwards, the third column should be used also in places where proper attention is not paid to the rams and their air vessels properly recharged when necessary.

In many parts of the country the problem of supplying mansions with water presents great difficulties. The quantity may be unlimited, but the quality not at all suitable. Or a limited quantity of good quality may be available, but not nearly sufficient to work a hydraulic ram. In a case of a small supply of good water and a plentiful supply of another kind, which would not be suitable for domestic purposes, being available, and circumstances are favourable, an especially constructed ram can be used and worked by the unsuitable water to raise that which is good.

Fig. 30 is a section of such a patented appliance. In the drawing F is the body pipe to an ordinary ram, the dash-valve of which was shown by Fig. 20, and delivery valve by Fig. 26. G is a continuation of the body pipe, and H is an indiarubber diaphragm, the edges of which are securely fixed between two flanges so that no water can escape either from below upwards or *vice versâ*. I is an inlet valve over the end of what may be called the suction pipe which is continued to a well or clean water reservoir fed by springs. At J is a valve opening upwards into an air vessel similar to the other one, and a pipe leading to the storage cistern or reservoir.

The action is as follows : Impure water entering the body pipe F escapes out of the dash-valve K, which is open, and by its momentum quickly closes the latter. The water no longer flowing freely away, having had its escape suddenly arrested, the impetus is expended on the under side of the diaphragm H, which is pushed upwards and forces the water in L through the

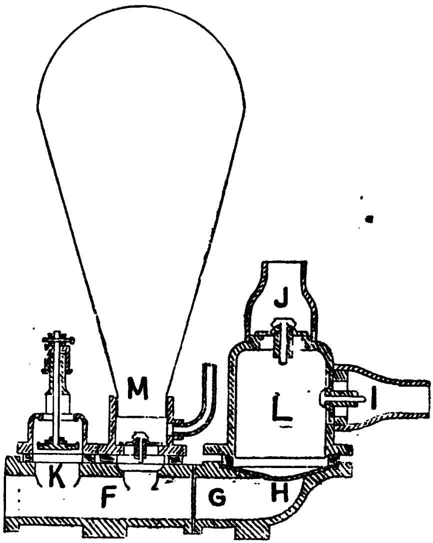

FIG. 30.

valve J into the air vessel and delivery pipe above it.

When the recoil of the drive water takes place the diaphragm H is drawn downwards, leaving a vacuum in L, which is filled with pure water through the valve I from the well or spring. And this is continuous so long as the ram is at work and the water supply sufficient.

The two waters are separate and cannot mix, nor can the dirty water be sent up to the mansion so long as the diaphragm is in good condition and free from defects.

The air vessel and valve M can be omitted, but if it is desired to send the foul water up to a farmstead or garden it should be retained and the necessary delivery pipe attached.

The two parts of the ram are bolted together by means of flanges, but if desired to be single acting, so that a portion of the water which works it only is raised, the parts G L are omitted, and a blank flange bolted on to the open end between G and F.

When used as a pumping ram only, the whole force of the drive water is expended on H, but when used as a double ram, so that clean and foul water are both raised to their respective positions, the force is divided, part being expended on H, and the other portion in pushing water through the delivery valve in M. In other words, if a single action ram was capable of raising 1,000 gals. per day, the double ram would raise nearly the same quantity, but half would be foul and half clean water. And these would be delivered in opposite directions, or to wherever the pipes were fixed.

The pumping ram will raise water from about the same depth as an ordinary pump, and the distance should never exceed 25 ft. in vertical height between the water and valve I. With a lesser height better results are obtained.

Another pumping ram is shown by Fig. 31. A speciality in this case is that it is impossible for the two waters to mix. This is a pumping ram only, and does not raise any portion of the water that works it, but only that which is desired.

To describe the appliance: N is the inlet and O the dash-valve, similar to those of an ordinary ram; P is a water-tight piston working in a cylinder, and having a rod Q to connect to a second and smaller piston in the cylinder R, the piston being pushed downwards by the compression spring S. The air vessel T has a delivery valve U at the bottom and over the body pipe V. A sucker valve with stop is fixed at W over the suction pipe X, and Y is the delivery pipe leading to a cistern or storage tank.

The action is as follows: The unsuitable

water entering at N escapes at O until an attained velocity suddenly closes the valve, when the force is expended on the bottom of the piston P. This raises also the piston R and

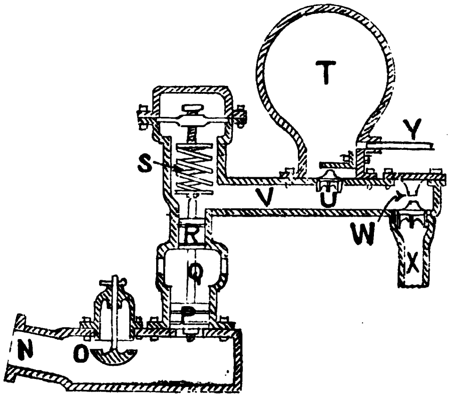

FIG. 31.

forces clean water out of V through the delivery valve U into the air vessel, and thence to the storage cistern.

As soon as the force of the drive water is expended the spring S presses down the pistons, leaving a vacuum in V, which is again filled with pure water through the sucker valve and pipe W and X.

The water is raised by what is really a force pump, with a solid piston or plunger adapted to work automatically by the shock of flowing water.

Another ram specialist has patented a pumping ram, as shown by Fig. 32. The dash-valve is not shown in the figure, as it is behind the parts illustrated. Its form was shown by Fig. 23. In the figure Z is the body pipe filled with impure water, which is subjected to shock by the closing of the dash-valve as in an ordinary ram. A is a piston sliding in a cylinder, and B is a connecting link to a smaller piston C. The pistons are pushed down by the arm D, which

is hinged at E. On the same axle are two weighted levers F (one only can be shown in the section), G is a sucker valve over an opening to which the suction pipe is attached, H is the delivery valve in the air vessel I, and J is the delivery pipe leading to the storage tank.

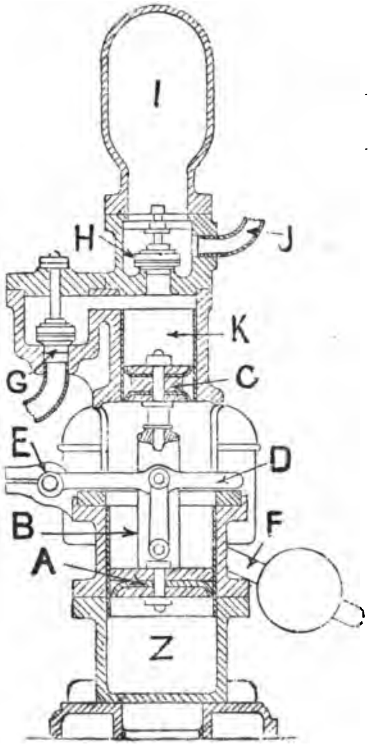

FIG. 32.

The ram works as follows: As soon as the working valve is dashed onto its seating, the water in Z is compressed sufficiently to raise the pistons A and C, and also the weighted levers F. On rising, the piston C pushes the

water out of K through the delivery valve H into the air vessel, and thence through the pipe J. As soon as the shock of the drive water is overcome, the weighted lever F actuates lever D, and presses the two pistons A and C down to their original positions, leaving a vacuum at K, which is again filled with water through the sucker valve and pipe at G.

With this appliance the waters cannot mix, nor the clean or pure water be contaminated by that which works the ram.

In the two foregoing appliances the pump pistons or plungers had their direction of travel

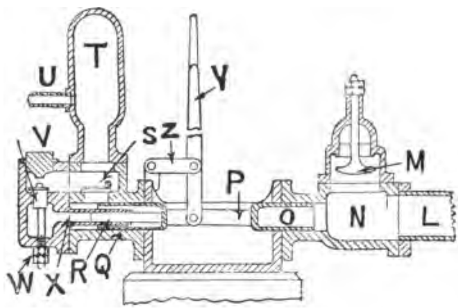

FIG. 33.

reversed, to form a vacuum in the suction chamber, by means of springs or weighted levers. Efforts have been made to obtain the same results by the pressure of water, and Fig. 33 is a section of a patented appliance for that purpose.

In the drawing, L, is the drive-pipe, supplied with foul water for working the ram; M is the dash-valve over the body pipe N; O is a piston with a connecting link P to a second piston Q. This latter is hollow, with a plunger, R, inside. The hollow piston works in the larger cylinder, which may be termed the "barrel," and the plunger in a smaller cylinder X, as shown in the figure. A sucker valve and pipe are attached to the larger cylinder, but are not shown in the figure. At S is the delivery valve opening into

the air-chamber T, and U is the delivery pipe; V is a small valve through which some of the water is forced when the ram is working, and which does not quite close, the adjusting screw W regulating the size of the opening; Y is a lever with connecting link Z, for working the ram until sufficient water has been raised to form a head for pushing back the plunger R, or for working the ram by hand in cases of emergency, such as failure of the working supply.

The action is as follows:—The driving water acts upon the dash-valve M in the same manner as with ordinary rams, and the shock drives the piston O, pushing the piston Q and forcing clean water through S, the piston sliding past the opening, thus gradually closing the orifice and minimising shock in the body pipe.

As soon as the force of the driving water is expended a portion returns through the small valve V into X, and pushes the pistons back into their original positions. The force of this back pressure is equal to the head of water in the delivery pipe acting upon the end of the solid piston R.

In a modification of the same patent the opening or connection between the valves S and V is omitted and a pipe substituted for the plug over the valve V, continued to a small tank fixed at the necessary height for giving sufficient head for pushing back the pistons. In this arrangement the same back-pressure water is constantly re-used and simply rises and falls in the pipe leading to the tank at each to-and-fro movement of the pistons. With this latter arrangement there may be said to be three water supplies, namely, that which drives the pistons forward, that which pushes them back, and that which is pumped. The back-pressure tank can be filled by hand or any other means, and as there is no waste of the water, would require very little attention.

All the pumping rams that have been described are limited in the depth from which they will raise water, in the same manner as any other kind of pumps, the limit being as was given when describing Fig. 30.

In many places the water supply is very limited and not sufficient for continuously working a ram. Or the supply may be plentiful during certain seasons and become reduced in others which are drier. This is especially the case when fed from intermittent springs, or when the water has to be collected from a catching area similar to that shown by Fig. 4.

In such cases the feed water tank or reservoir, where possible, has to be of a good size for storing the supply when plentiful. But there are many places where this is impracticable, or

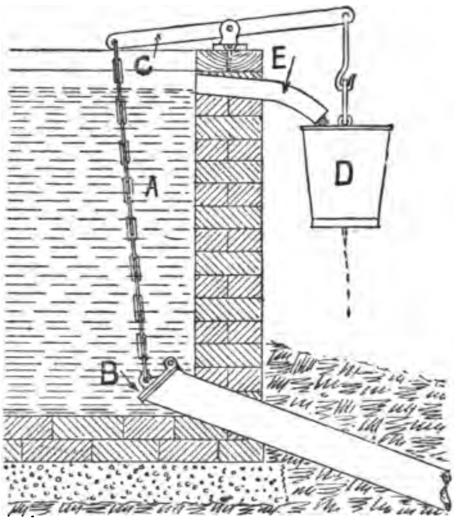

FIG. 34.

where the water could not be stored at a sufficient height for giving the necessary head.

Where the ram is "close at home" so that it can be frequently visited, the valve shown by Fig. 5 can be dropped by hand when the supply is exhausted, and again opened when the tank has re-filled.

But when a mile or two away from the house such attention cannot very well be given, and it

becomes necessary to fix an automatic acting arrangement for closing the valve when the supply fails to yield sufficient for working the ram, and re-opening it when the water has again accumulated.

Fig. 34 is a sketch section of a primitive appliance the writer once saw and which was found to be answering fairly satisfactory, although some of the water was wasted. In the sketch A was a brick built tank, filled by small springs in a wood, B a drop valve with a chain to the hinged lever, C. On the outer end of the lever a bucket, D, was suspended and this was filled when the tank overflowed through the pipe, E. The full bucket was heavy enough to pull down the lever and open the valve.

The bucket had a small hole in the bottom so that, when the tank ceased to overflow, it gradually emptied, allowed the valve to close, and thus stopped the ram from working. When the tank again overflowed and filled the bucket the valve was again opened and the ram re-started.

On studying the arrangement it will be noticed that so long as the supply is plentiful the ram will work, but will stop when the tank ceases to overflow.

Without it the dribble into the tank during a dry season would flow away through the ram, as the force would not be sufficient to close the dash-valve, and be wasted; but with it a small portion is raised by the ram, and that is far better than having none at all.

A better appliance than the bucket with the hole in the bottom would be to suspend a properly-constructed rectangular vessel, with guides to keep it steady and a syphon pipe arranged for automatically emptying the contents back into the feed tank when the water in the latter had lowered to a certain level. This would save a few gallons from being wasted each time the supply ran short, and also enable the counterpoise to act more quickly. Neither would any of the water be running to waste when the counterpoise tank was filling.

A much better arrangement is the patented appliance shown by Fig. 35. In the drawing F is the body fixed on the end of the drive pipe in the feed tank, G is a valve fixed on the lever, H, which is attached to another lever, I, and which is hinged at J. At the end of the latter lever is a copper ball, K, with a stem pinned to the lever, I, and which can be adjusted to any desired length. The left-hand end of I is cranked, and to it is attached a spindle, L, with a weight, M; N is a jointed stud hinged to I

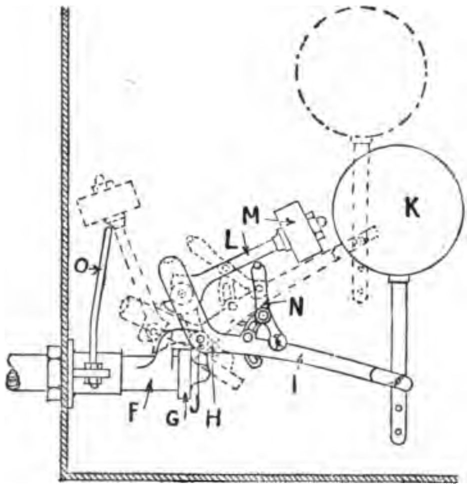

FIG. 35.

with a slotted cam arm and adjusting screw. A small roller on the top of N supports the weighted spindle L, and O is a rest for the latter when the valve is open

The action is as follows: Assuming the details to be in the positions shown, the valve G is shut and no water can flow down the drive-pipe, F, the tank being nearly empty. As the tank fills the ball, K, rises to the position shown by dotted lines and raises the lever, I, with the attachment, N. This presses against L and pushes it

upwards until the whole is sufficiently high for the weight, M, to be beyond the centre of gravity and it falls against the rest bar, O. This part of the motion is so sudden that the valve, G, is quickly opened, the force being sufficient to overcome not only the outside pressure of water against the valve, but also the weight of that inside the pipe.

When the tank is filled, and contains sufficient to work the ram, the whole of the arrangements are as shown by dotted lines; but if the supply fails, the float, K, lowers and actuates the various levers until the weight, M, is on the reverse side of the centre of gravity, when it falls forward and closes the valve, G, as shown by firm lines.

There is no doubt that this is a valuable appliance for using where the supply to a ram is meagre or intermittent, as not a drop of water need be wasted.

Hydraulic rams are almost invariably fixed at some distance from the dwelling, sometimes a mile or two away, and it follows that they should be protected not only from frost but also from injury by cattle or men or boys led by curiosity to tamper with them.

The best position is in an underground chamber; when very deep the entry being through a trap-door in a frame at the surface, or a few inches above ground level, and an iron ladder, or step-irons, built in the wall, either of which occupies but little room, for getting down

When the ram is nearer the surface the entrance can be by means of outside steps built at the same time as the ram house, a door hung to open inwards, and a drain made for taking away rain water from the bottom landing.

In some cases it is necessary to fix wood flaps over the stairs or steps, or a railing for preventing cattle falling down. The former is the best, as in the winter time it is easier to clear the snow off the covers than to dig it out from the sunken steps should the ram require attention. Underground houses are best built circular on plan and have domed brickwork, or stone roofs.

The diameter should be from 4 ft. to 6 ft., according to the size of the ram, or if duplicate rams are fixed; and the height should not be less than 6 ft. if possible to get it.

When the ram can be fixed above ground a house about 8 ft. × 5 ft. inside measurement is a convenient size. Such houses have to be roofed, and plain tiles or stone shingles are good for the purpose. In a house of this kind the writer had to do with, the roof was boarded, then felted and battened before tiling, for keeping out frost. In the gable ends, openings were left for ventilation, but these were afterwards blocked up for keeping out birds, with the result that in about three years the rafters and boarding began to rot. The reek, or vapour, from the water could not escape, with the results as stated.

Incidentally it may be mentioned that the water to hydraulic rams very rarely freezes so long as they are working, and even during the coldest weather it is not necessary to stop up all ventilation in an above-ground house. It is, however, advisable to have all openings above the level of the ram, so that a sharp current of cold air cannot impinge against it.

The entrances to ram houses of any kind should be locked, and for this brass padlocks or oak rim locks are the best.

As the greatest force of the water shock occurs near the ram it is important that the latter should be well fixed, either to an oak base secured with concrete, or to a stone or concrete floor. The force of the water has a tendency to push the ram from the drive-pipe, and by fixing the former an opposing force is offered. Under great heads the leaded joint to the body-pipe is sometimes blown, and the flanged connections to the ram or stop-valve broken.

All ram houses should be paved and drained and provision made for the tail water to flow freely away. Although some rams will work when flooded or with the dash-valve under water, they will do so much better when there is no back water to interfere with them.

As all rams are manufactured by specialists it is very difficult for plumbers to properly repair them unless they have the proper fittings. Many at work have been repaired and parts replaced with totally unsuitable pieces. Such rams are always in trouble, and the cost of frequent repairs is a permanent tax on their owners. In one instance the writer saw outside a ram-house no less than nine old iron dash-valves. Their number and variation in size and weight was proof that the ram had been a considerable source of trouble.

When ordering a new ram, the working parts or valves should be in duplicate, so that when one is much worn or breaks down it can be exchanged in a very short time; the broken or defective valve being sent to the makers and repaired, or renewed if necessary, ready for refixing when occasion requires. Not only is there a saving in the cost of repairs, but the plumber who has to do the work gives more satisfaction to his client and the reputation of the ram maker is not injured. It may be added, this applies to all kinds of especial fittings used by plumbers.

Country, especially estate, plumbers have advantages over those who work in large towns in that they frequently have to do a great deal with rams. There is many a ram fixed which may be said to have a "temper of its own," and the plumber who is usually called in to adjust, or repair it, can often succeed much better than a stranger would in making it work properly.

If all rams were exactly alike and worked under similar conditions, rules could be formulated for their fixing, adjusting or regulating. But as the conditions vary both with regard to size of ram, quantity and head of drive water, length and size of drive and delivery pipes, and the quantity and height delivered, it follows that each one has to be studied under its especial conditions. There are a few empirical rules, or those based on practical experience, but they are only suitable for conditions which are exactly similar in all details to those from which they were deduced. At the same time they

form a basis for making calculations which, if not exactly, are approximately, correct.

Sometimes a machine will work satisfactorily for a time and then stop, there being some difficulty in finding the reason. In many such cases experiment will often succeed when theory fails. But it must be admitted that the plumber who knows the theory will be better able to make the right experiment than the one who is ignorant of the principles upon which the working of rams is based.

One great cause of rams stopping working, after being in use for some time, is the reduction in area, and roughness inside, of the drive pipe caused by rusting. The head of water may be sufficient for dashing the valve onto its seating, but the force of the recoil is so small, by reason of excessive friction in the drive pipe, that the valve will not open properly for the next stroke to be efficient. In some such cases the valve will, at times, be found to chatter; and a ram with a chattering dash-valve is always uncertain in its action and liable to stop.

The writer once found the drive-pipe to be lined inside with a kind of slime, and this was traced to ducks being kept in the small lake which supplied the ram. On passing a small bundle of fine wire netting through the pipe the slime was removed and the ram then worked properly.

If the drive pipe leaks the water will not recoil sufficiently to open the dash-valve and the ram will cease working.

Air in the drive pipe has an injurious effect. "Clear" or "straight-way," valves should always be used, as has before been explained. Ordinary stop valves with a circuitous water-way through them should never be used, as a small quantity of air is frequently pent up inside and cannot escape.

The extra friction of the water when passing through a bend, especially when fixed near the ram, will sometimes affect the recoil and cause the dash-valve to hang up.

Some of the patented rams have long or short strokes, and adjust themselves to the work

they are doing. But those of ordinary make have to be regulated, by washers or screws, according to the length of the drive-pipes and heads of water above the rams. In such cases the length of stroke should be so regulated as to be as long as possible, as a ram with a short stroke is more liable to stop than one which has a longer stroke.

When an air-vessel is water-logged the resistance is so great that the delivery valve will not open, and this will sometimes stop the ram, owing to an insufficient recoil of the drive water.

In one instance the height to which the water was delivered was so low, and the air pressure inside the vessel so small, that when the shock of the dash-valve took place water was pushed through the delivery-valve for a second or two afterwards. This resulted in the momentum of the drive water being slowly arrested, and there was no recoil. By constantly pushing down the dash-valve by hand a considerable quantity of water was raised, but when left to itself the the ram immediately stopped.

A case almost similar to the latter, in a Midland county, was for a time a considerable cause of anxiety. Two rams were fixed in a pit about 15 ft. below ground level in the position shown at P, Fig. 36. Q, R, and S were cisterns averaging about 1,000 gals. each, fixed in brewhouse, stables and mansion at heights of about 35 ft., 25 ft. and 65 ft. respectively above the ram; R in the stables was about 100 yards distant. The water supply was only sufficient for working one ram at a time, the other being in reserve in case of a breakdown. They were both connected to the same rising main, but had separate drive-pipes. Ball-valves were fixed to Q and R, but the pipe to S had an open end.

Each ram could be regulated to raise water to either cistern separately, but not to fill all of them in succession. When adjusted for filling the highest cistern the ram immediately stopped when water ran into the lowest cistern, and *vice versa.*

Experiment having failed to solve the problem, it was decided to calculate the flow-energy exerted on the ram and compare it with the work done in raising water to each cistern respectively, and the result showed a wide difference.

As the rams would do what was required to each cistern separately, it was considered

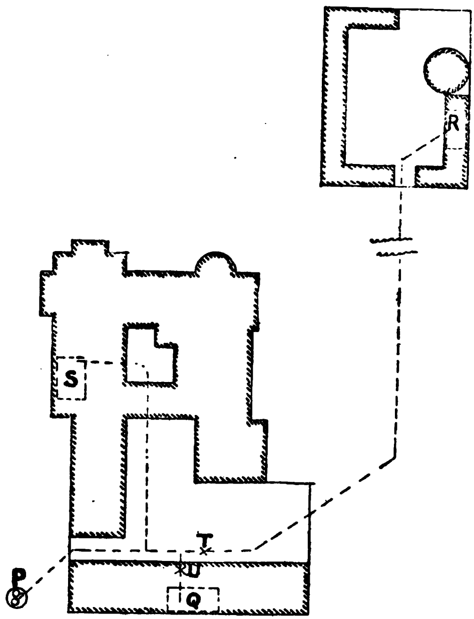

FIG. 36.

that neither they nor their drive-pipes need be altered, and the trouble could be overcome by making the work of raising water uniform to each cistern.

And to do this, square-headed stop-cocks were fixed at T and U and closed until the resistance, as shown by a pressure-gauge, was

found to be equal to each cistern. The rams then worked satisfactorily, and there was the further advantage that S always had water running into it and did not have to wait for its supply until the lower cisterns were filled. But when the latter were filled and the ball-cocks closed a stronger stream went up to S.

It may be added that ordinary stop-valves were fixed in the delivery pipes when necessary to shut off the supply to the cisterns and instructions given that the other, or regulating cocks, were never to be turned nor interfered with in any way.

Another cause of rams stopping working is a variation in the head of drive-water, and this is very common where supplied by intermittent springs. Or the supply may be so lowered that air is carried in with the water. In such cases the dash-valves will sometimes chatter for a few seconds and eventually remain closed ; or if the dash-valve is a very heavy one it will remain open.

When the leaded joints in a cast iron drive-pipe "blow," it is a difficult matter to make them sound. In some cases it is a real economy to go to some trouble and melt out the old lead and remake the joints, using rod lead instead of ordinary yarn. Two or three cold lead rings or bands, to be well caulked in, and the sockets then filled with molten lead, used as cold as possible so as not to shrink much, and then staved in the usual manner. Or the socket and spicket ends can be made red-hot to burn off anything which would prevent them rusting, and then make the joints with the rust cement which has been described.

There are many peculiarities attached to the working of hydraulic rams, and it is almost impossible to describe them all. The theory of their working may be clearly understood, but there are so many variations in their fitting up and the work extracted from them, that it may sometimes appear to be at fault. But upon giving further thought to the subject it would appear to be rather a difficulty in getting at all

the facts upon which to base it than that theory itself was wrong.

That hydraulic rams are valuable appliances, and under favourable conditions the most economical that can be used for raising moderate quantities of water, is evidenced by the number that are giving satisfactory results in various parts of the country.

And that those who have to fit up or repair them may have at least an elementary knowledge of their action and working is the object and aim of the writer in publishing these lectures.

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